Hyper-Kamiokande

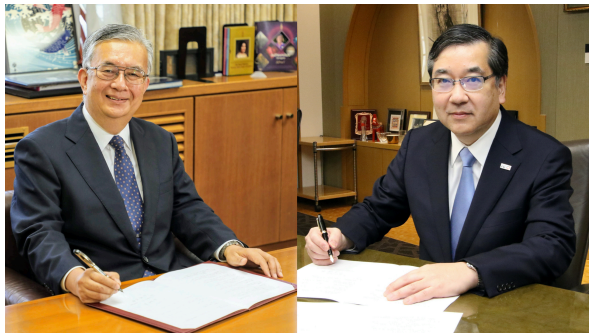
Masaki Ishitsuka (Tokyo University of Science)
on behalf of the Hyper-Kamiokande Proto-Collaboration

June 29th, 2020
The XXIX International Conference on
Neutrino Physics and Astrophysics

The Hyper-Kamiokande project is officially approved

2020 February : First year construction budget approved by Japanese Diet
2020 May: Univ. of Tokyo President and KEK Director General signed MOU

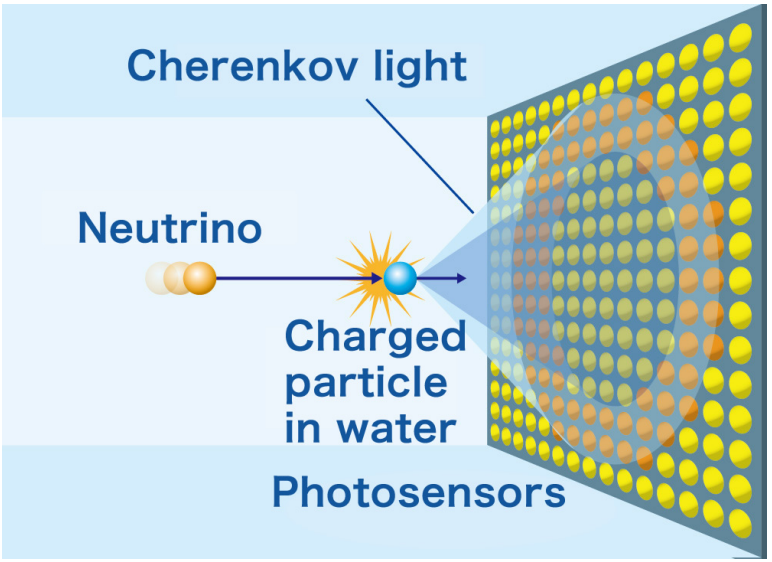
KEK will upgrade and operate the J-PARC accelerator to produce a high-intensity neutrino beam

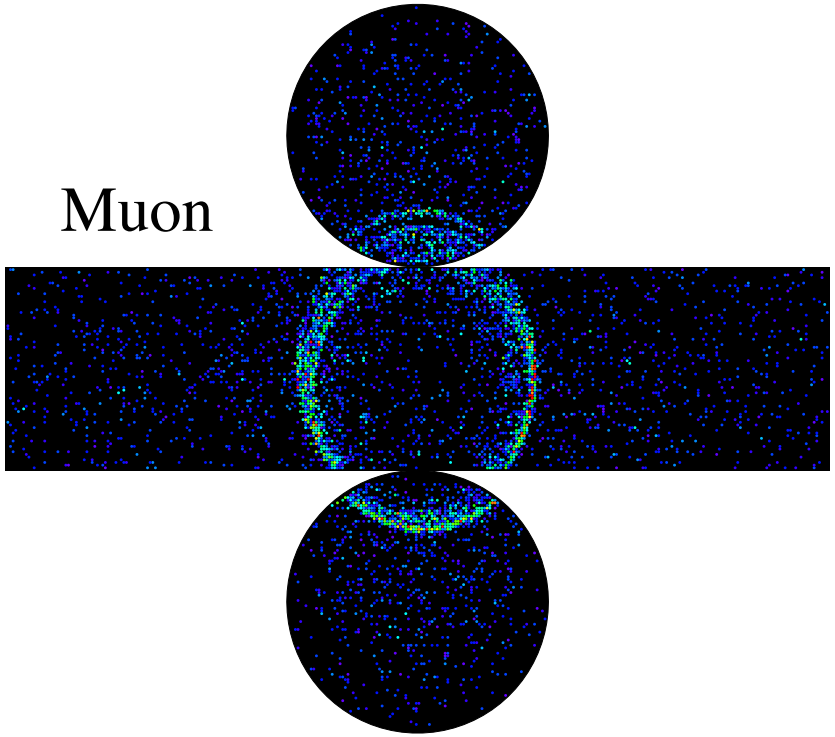


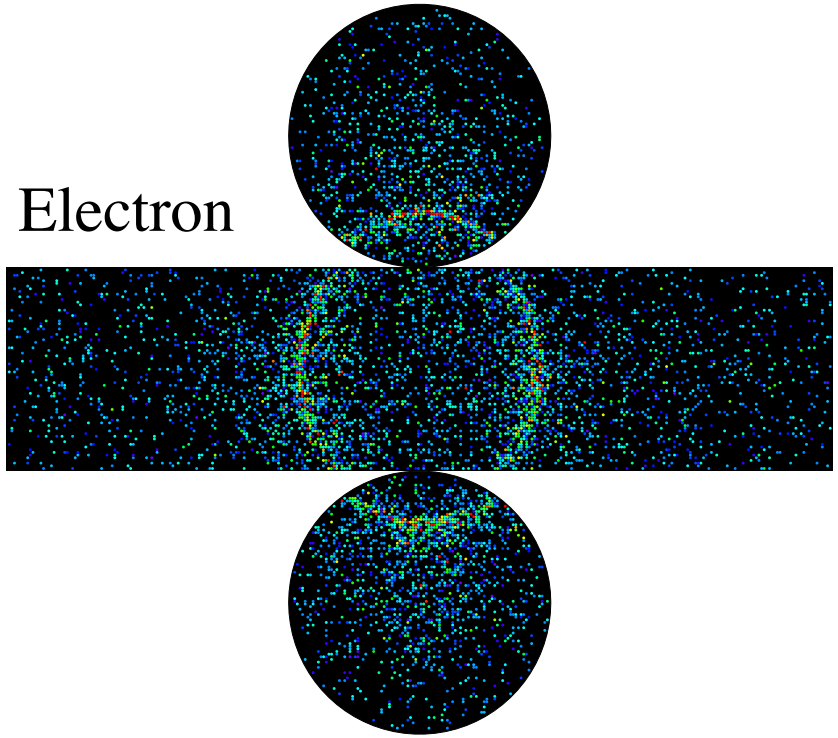
The University of Tokyo will construct and operate the Hyper-Kamiokande detector

Hyper-K is under construction
Operation will begin in 2027

Water Cherenkov detector

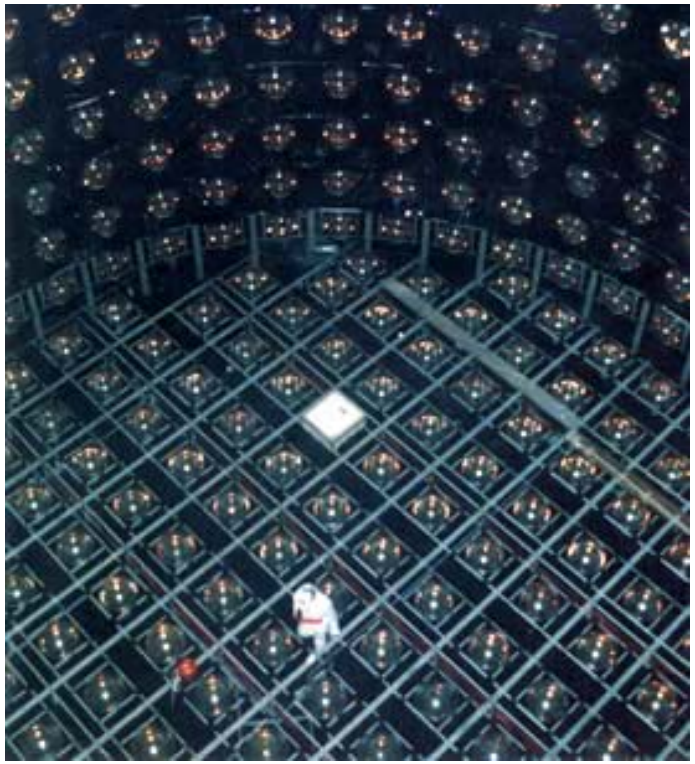






- Cherenkov ring
  - Particle identification (>99% efficiency for μ/e separation)
  - Momentum reconstruction (energy and direction)
- Scalable to larger mass ⇒ rare process (proton decay search and neutrino observation)
- Well established technology → next slide

3rd generation underground water Cherenkov detector in Kamioka

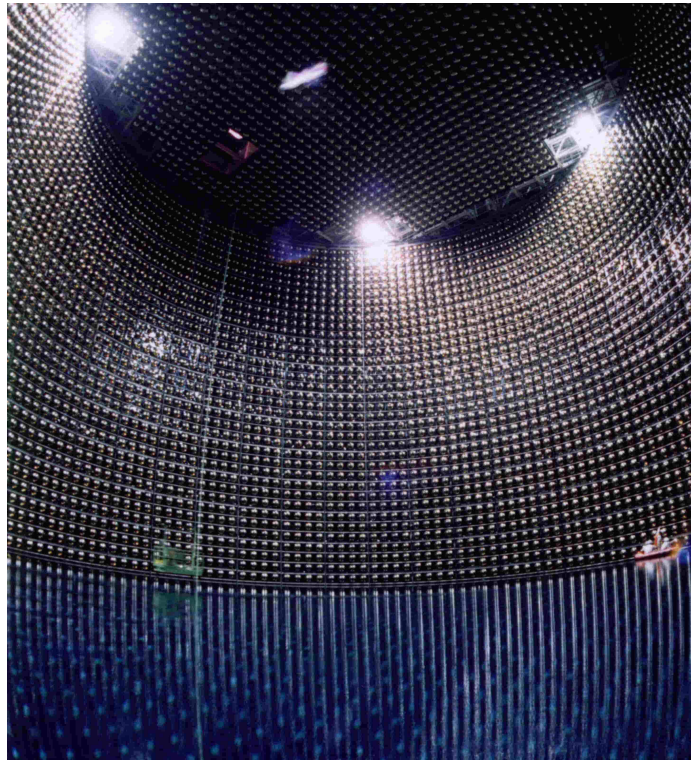


Kamiokande

(1983-1996)

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

Birth of neutrino astrophysics

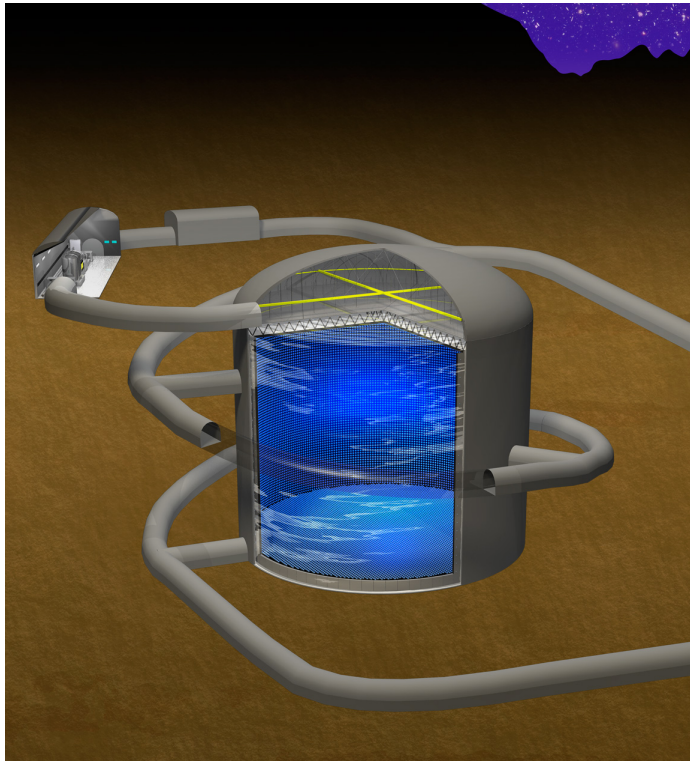


Super-Kamiokande

(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

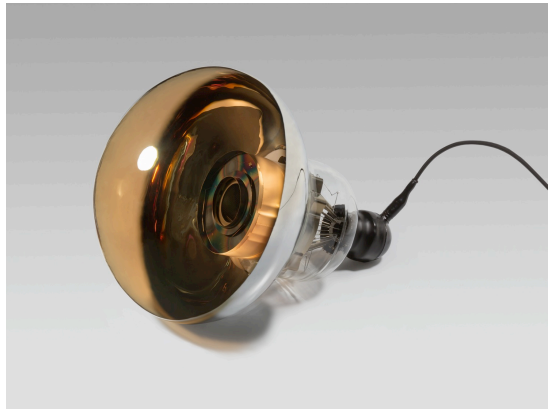
(start operation in 2027)

- Extended search for proton decay
- Precision measurement of neutrino oscillation including CPV and MO
- Neutrino astrophysics

Explore new physics

The Hyper-Kamiokande detector

High QE Box&Line PMT

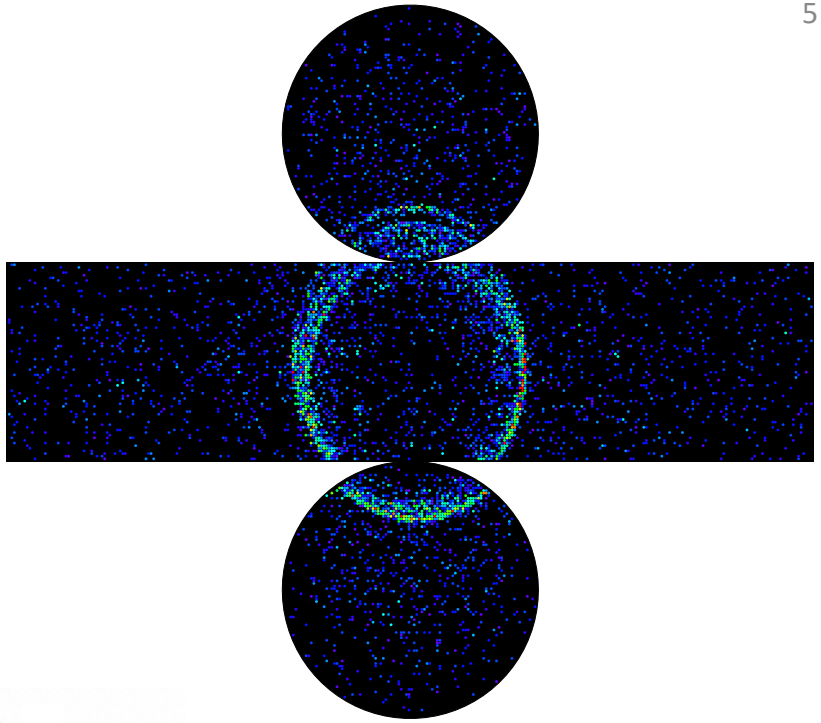


×2 pressure tolerance

×2 photon detection

×2 timing resolution

Precision measurement

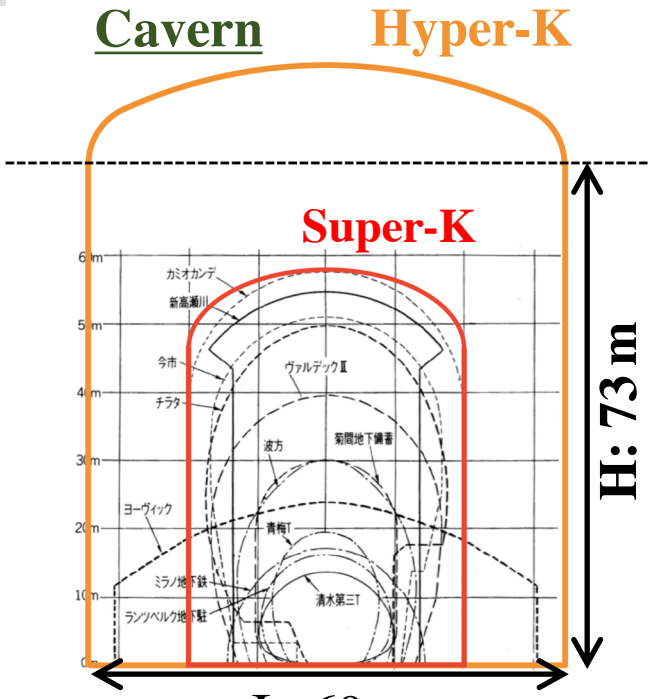


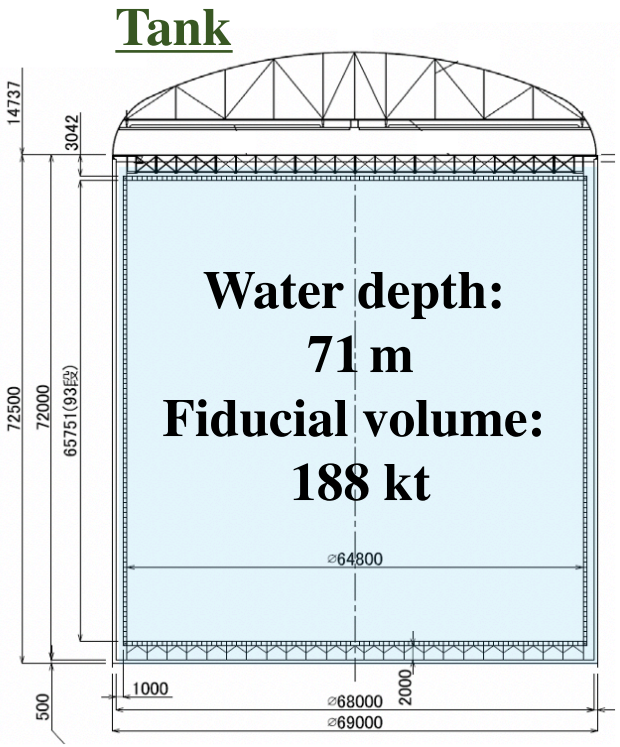
Recent update:

- Lower dark rate (similar level to SK)
- Lower radioactive contamination

New detector design (cost reduction)

R&D for large cavern

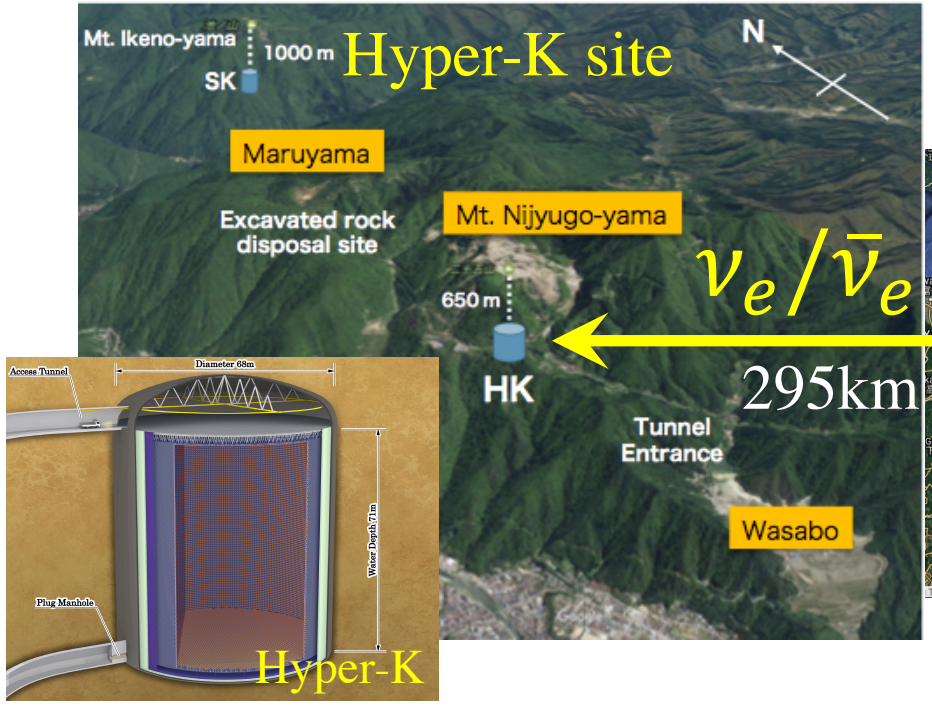




High statistics neutrino data

New detector design by synergy of different technologies

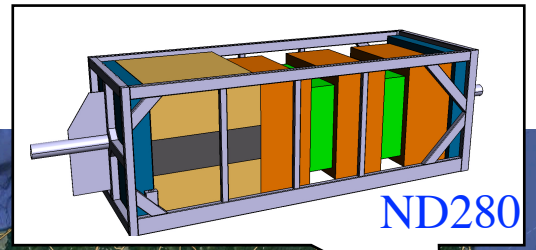
Experimental setup of Hyper-Kamiokande

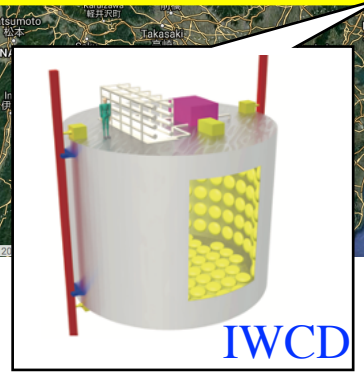


$\nu_e/\bar{\nu}_e$

295km

Near detectors





$\nu_\mu/\bar{\nu}_\mu$

J-PARC upgrade:
500 kW → 1.3 MW

	Super-K	Hyper-K
Overburden	1000 m	650 m
Number of ID PMT	11,000	40,000
Photo-coverage	40%	40% (×2 sensitivity)
Total/Fiducial vol.	50 / 22.5 kton	260 / 188 kton

× 8.4 fiducial volume (SK → HK)

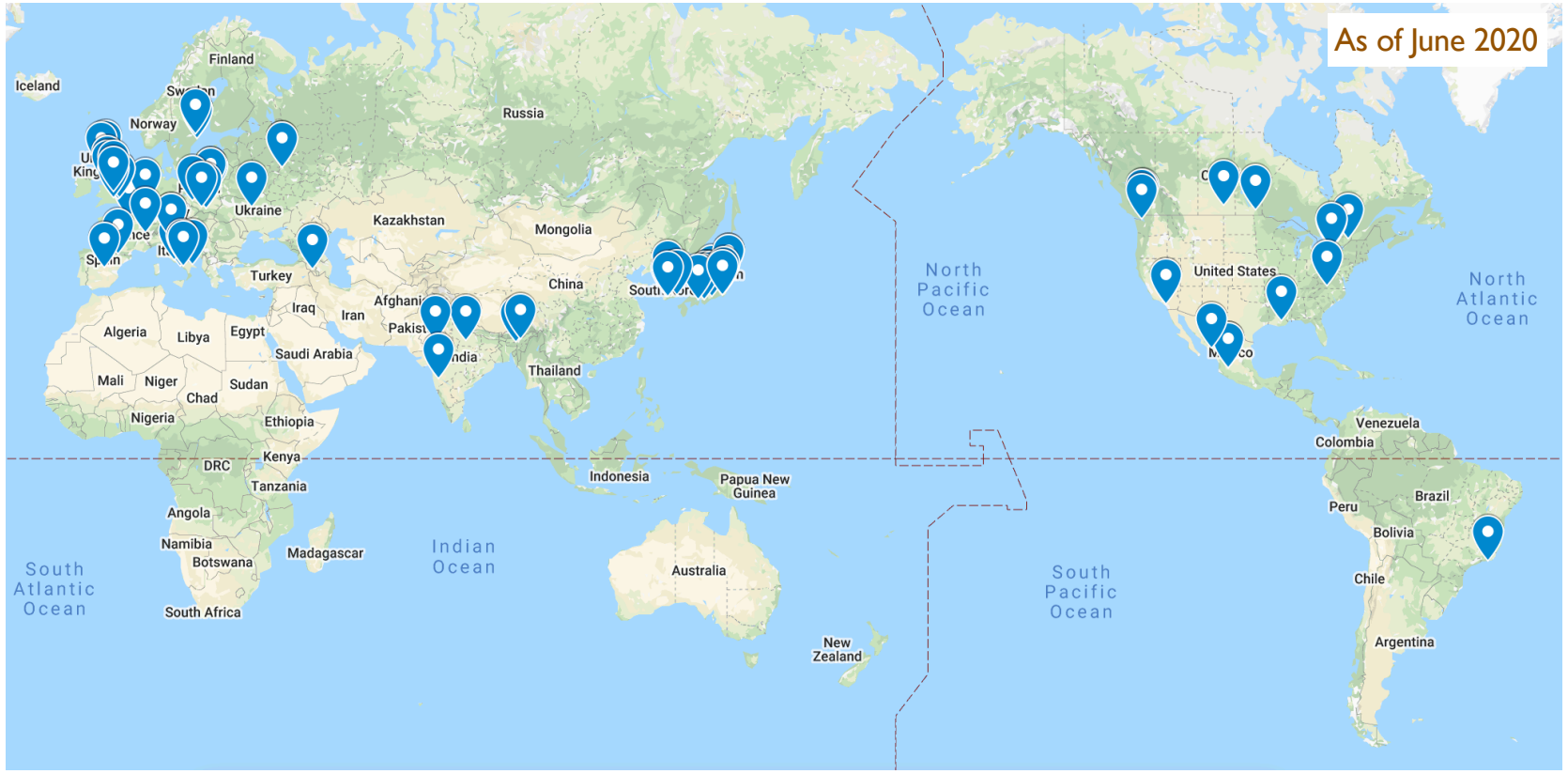
× 2.6 beam power (J-PARC upgrade)

→ **More than 20 times statistics**

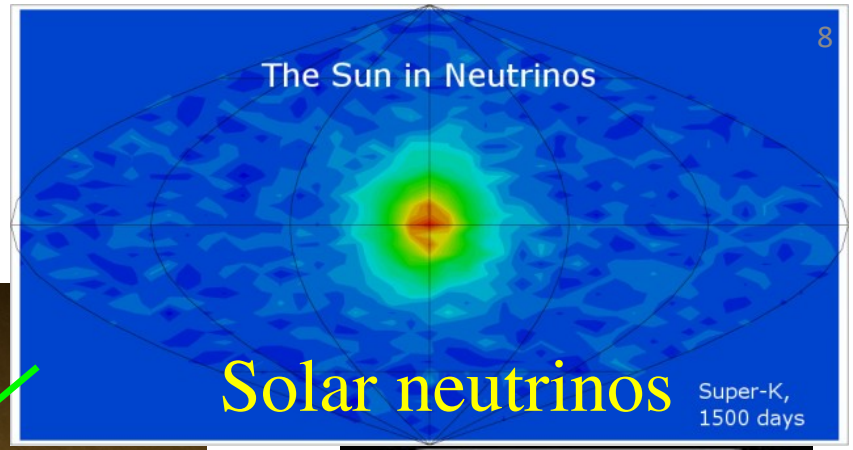
Hyper-Kamiokande Proto-Collaboration

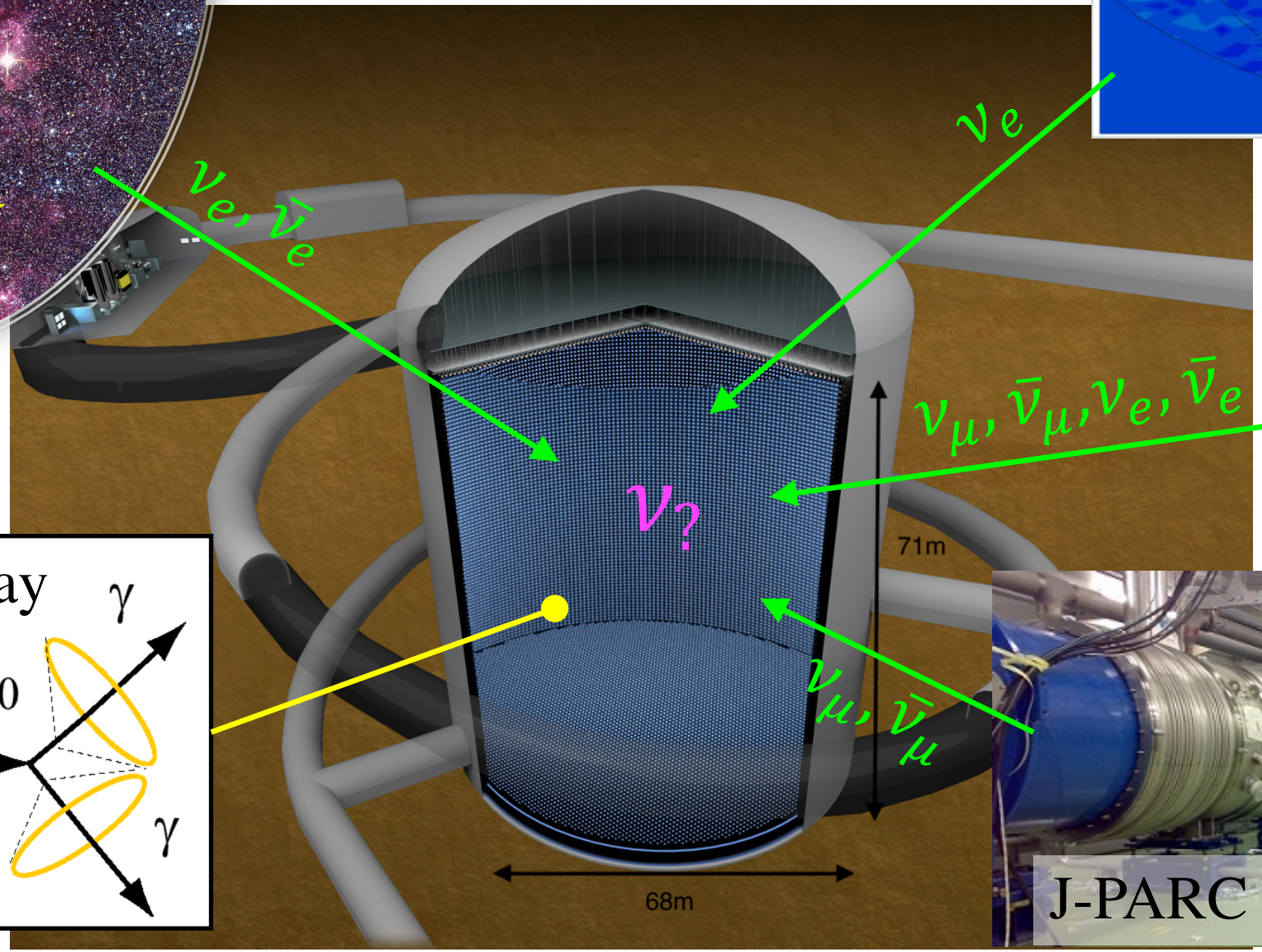
18 countries, 82 institutes, ~390 people

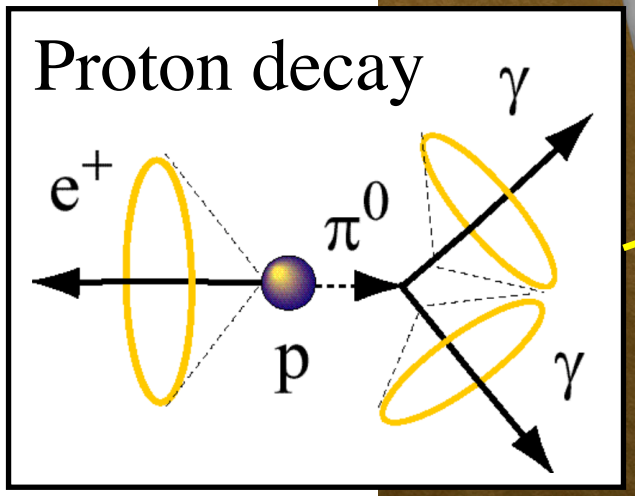
Hyper-Kamiokande



Physics in Hyper-Kamiokande



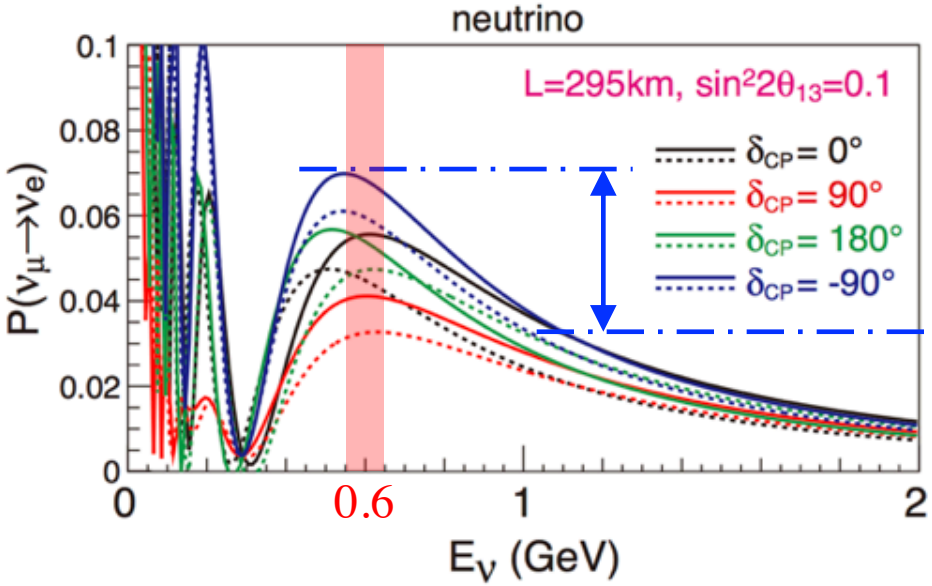


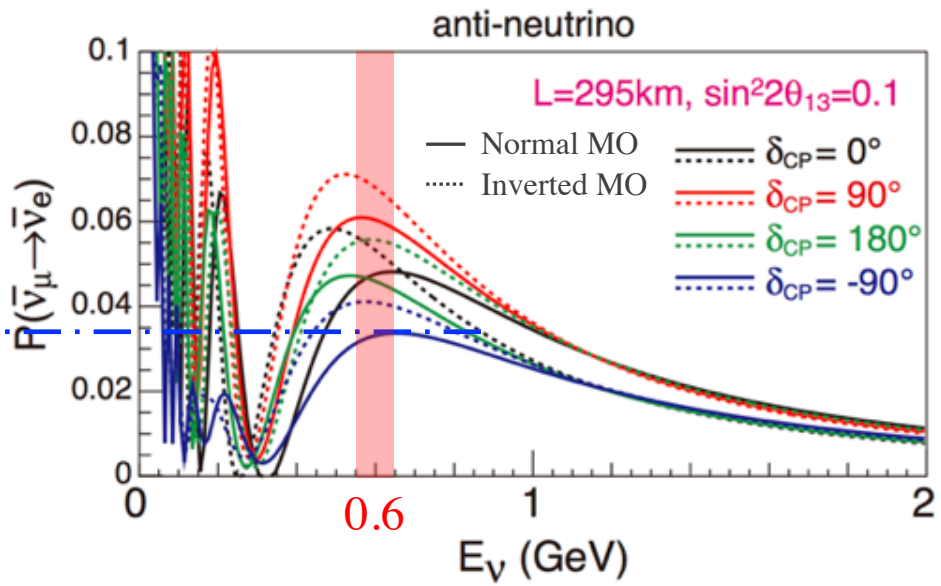


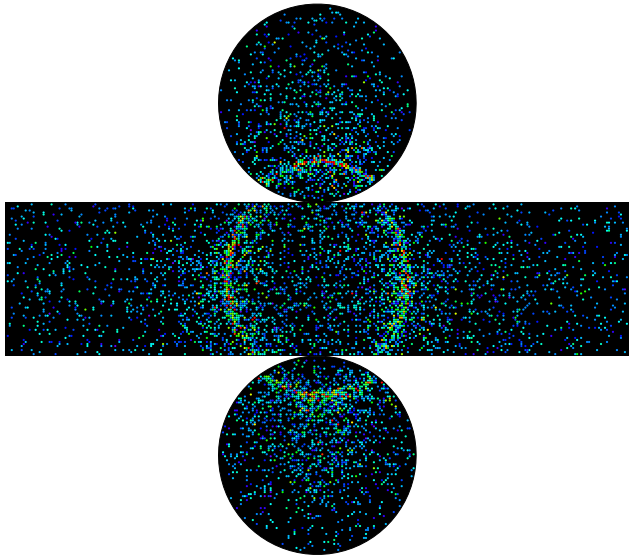
Long-baseline program with J-PARC neutrino beam

Experimental setup

- 2.5° off-axis ν_μ and $\bar{\nu}_\mu$ beam peaked at 0.6 GeV (oscillation maximum at 295km)
  - ➢ Major component is QE: E_ν determined from (p, θ) of outgoing charged lepton
    ↔ Suppress non-QE and NC contamination by selecting single-ring event
- Measures CP violation in neutrino sector from comparison of $P(\nu_\mu \to \nu_e)$ and $P(\bar{\nu}_\mu \to \bar{\nu}_e)$







- A few % statistical uncertainties after 10 years operation with >1000 ν_e and $\bar{\nu}_e$ signals
- Projected sensitivity based on T2K systematics uncertainties + improvements for HK

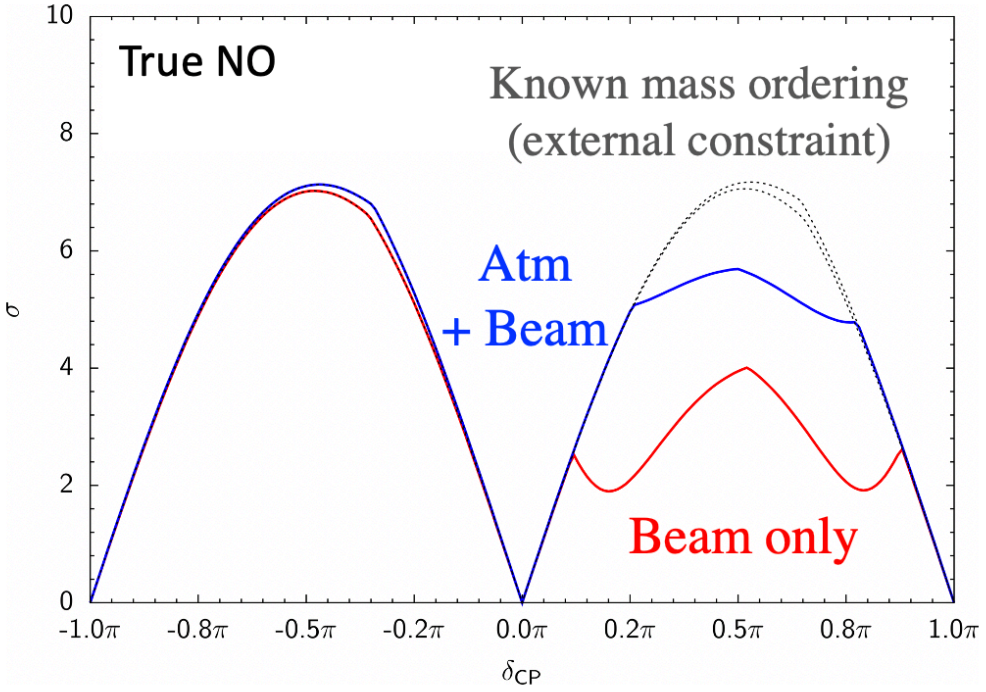
Strategy of Hyper-Kamiokande

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

	$\sin^2\theta_{23}$	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

10 years with 1.3MW, T2K 2018 systematic error

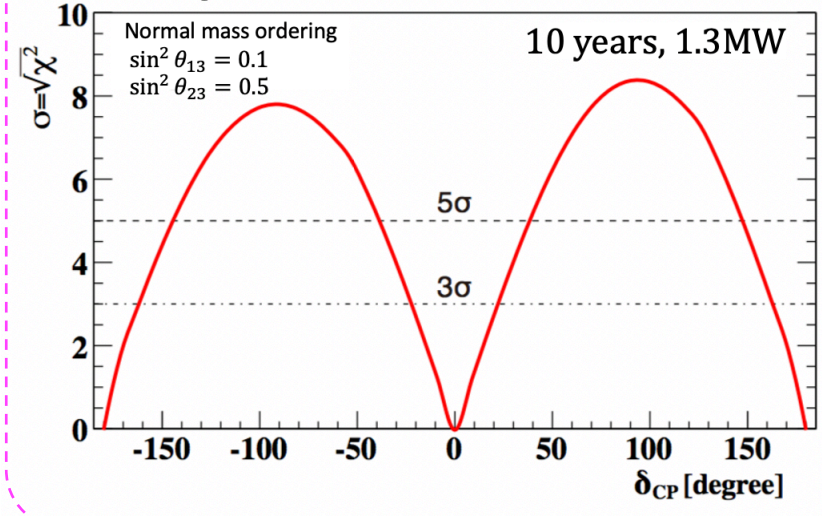


Atmospheric neutrino: sensitive to mass ordering by Earth's matter effects
→ Constraints on mass ordering enhance sensitivity to CP violation by long-baseline

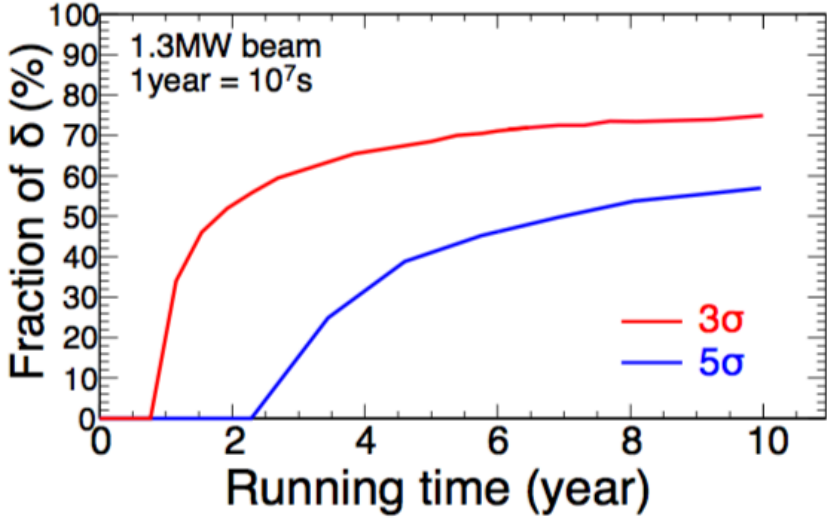
Precision measurement of neutrino oscillations

Syst. errors (T2K 2016 + improvements for Hyper-K) δ_{CP}

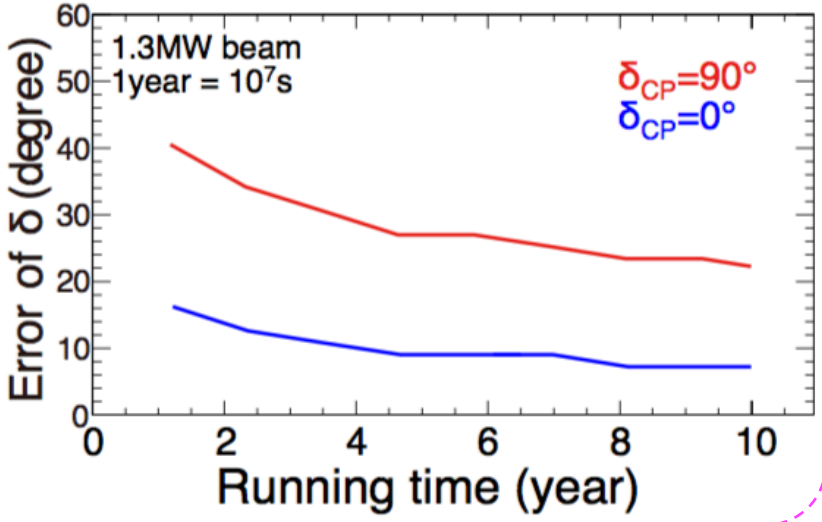
Significance to CP violation



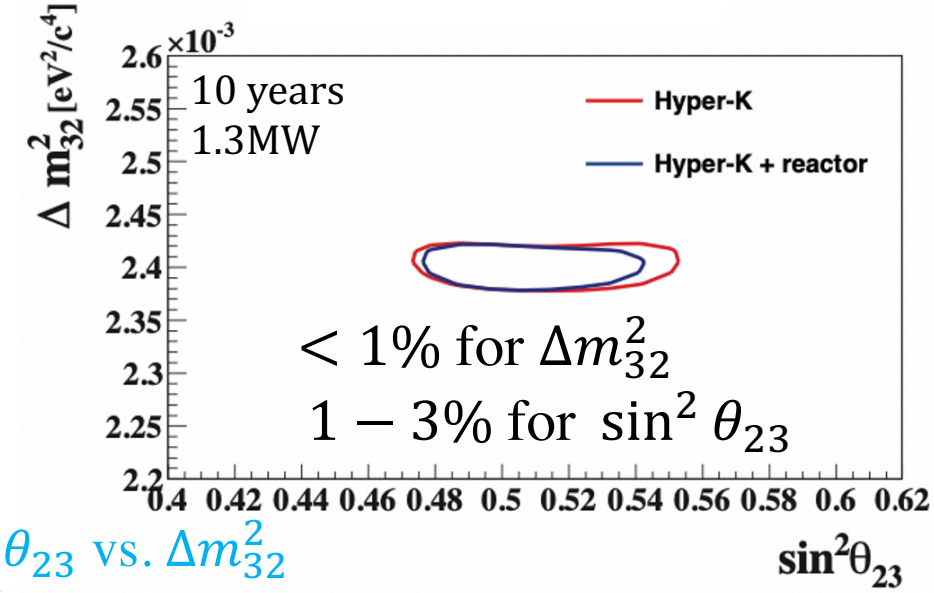
Fraction of δ_{CP} to exclude $\sin\delta_{CP} = 0$



Precision of δ_{CP} measurement

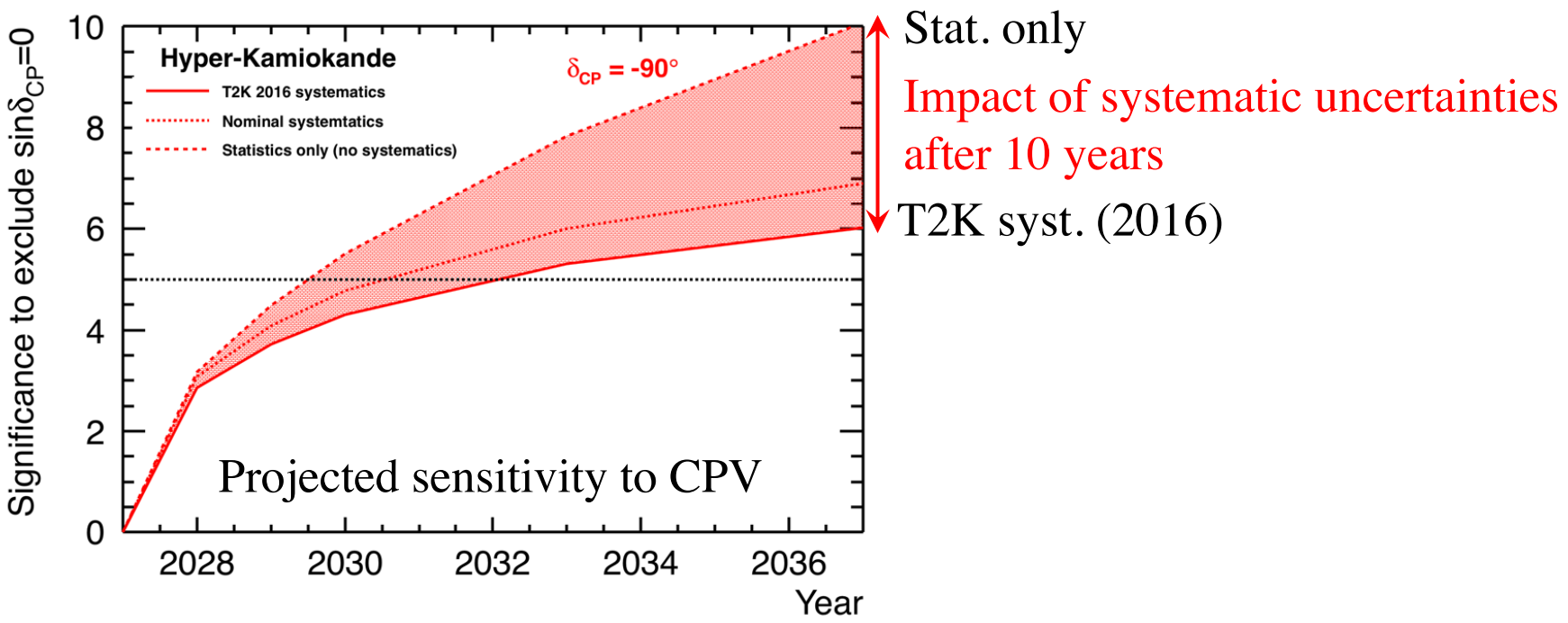


- Exclusion of $\sin\delta_{CP} = 0$
  - $\sim 8\,\sigma$ for $\delta_{CP} = -90°$ (favored by T2K)
  - Good opportunity to make discovery of CP violation in neutrino sector at >5 σ
- Measurement of δ_{CP}
  - $23°$ for $\delta_{cp} = 90°$ / $7°$ for $\delta_{cp} = 0°$



θ_{23} vs. Δm^2_{32}

Prospects for CP violation measurement



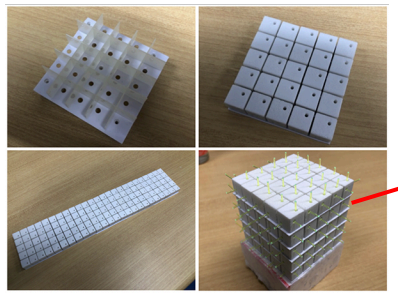
- **Reduction of systematic uncertainties** has impact to CPV measurement
  - Uncertainties on neutrino interaction models are major components ⇒ **Near detectors**
- **On-axis beam monitor (MUMON and INGRID)**
- **Off-axis magnetized tracker (ND280) with upgrades**
  - Constraints on beam flux, neutrino interactions, wrong-sign components , etc.
- **Intermediate water Cherenkov detector (IWCD)**
  - ν_e cross-section, E_ν vs. E_{rec}, NC and intrinsic ν_e BG , neutron multiplicity

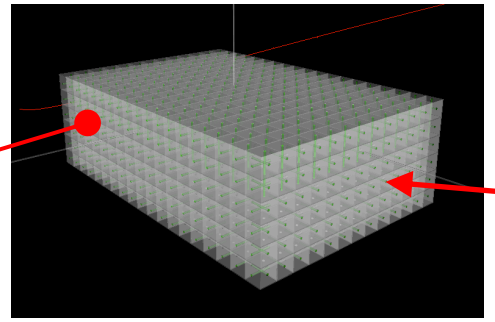
ND280 upgrade plan for T2K

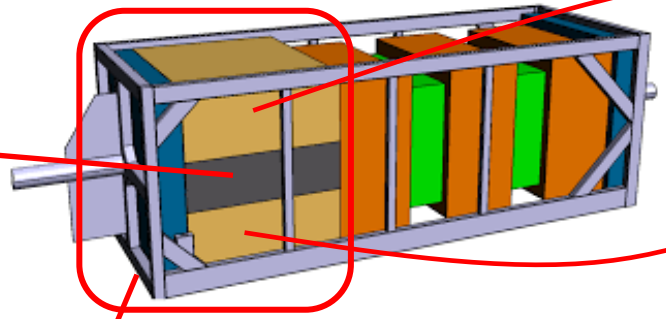
arXiv:1901.03750

There will be talk by Patrick Dunne on July 2nd "Latest Neutrino Oscillation Results from T2K"

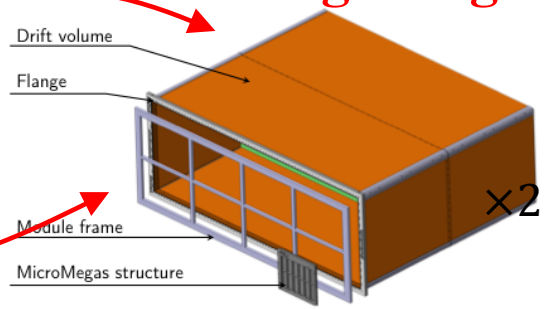
- **Large angle acceptance** to constrain neutrino interaction models
- Measurement of **short tracks** to identify non-QE, NC γ etc.







High Angle TPC

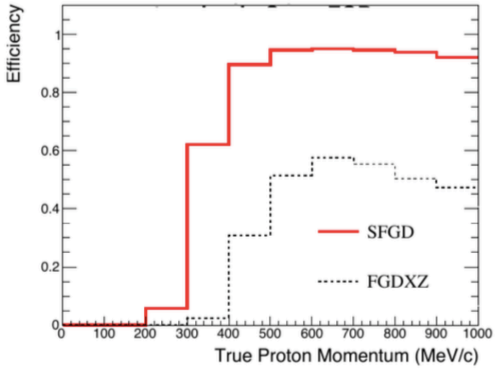


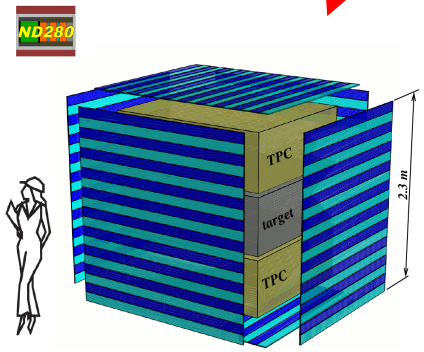
Improve reconstruction of hadron (short) tracks

SuperFGD

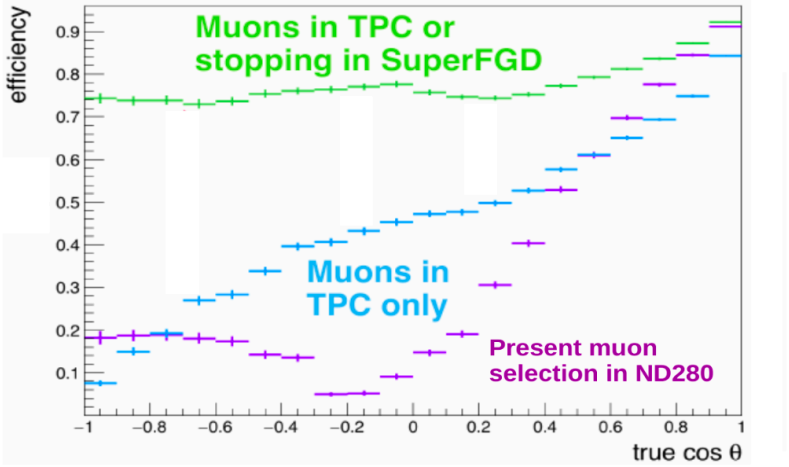
(scintillator target tracker)

~2m^3, ~2M cubes, ~60k ch





TOF

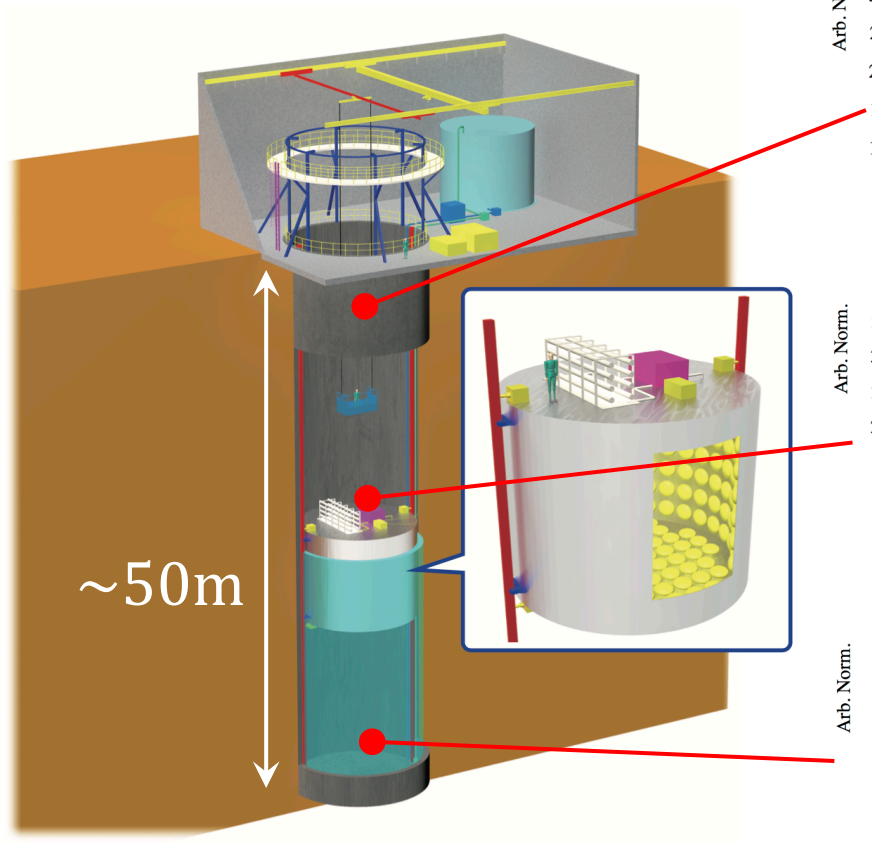


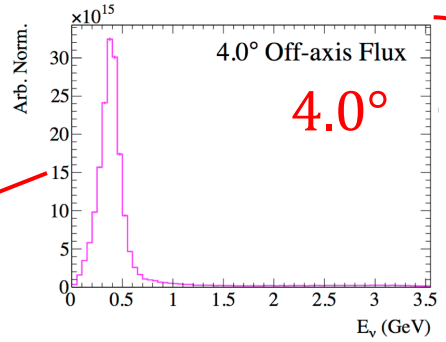
Hyper-K is planning to use ND280 after T2K has finished

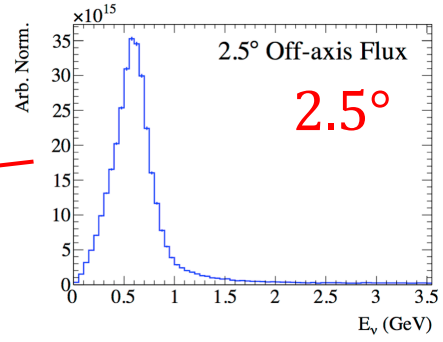
International contributions for further upgrades are welcome

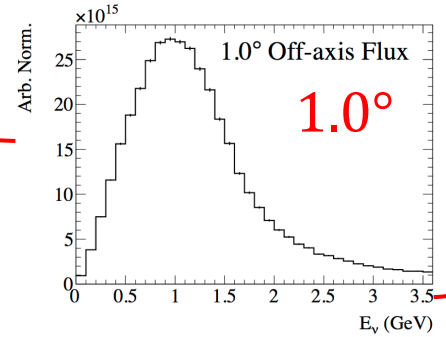
Intermediate water Cherenkov detector (IWCD)

- 1kton scale water Cherenkov detector at ~1km baseline
- Detector can vertically move ⇒ measurement at different off-axis angles





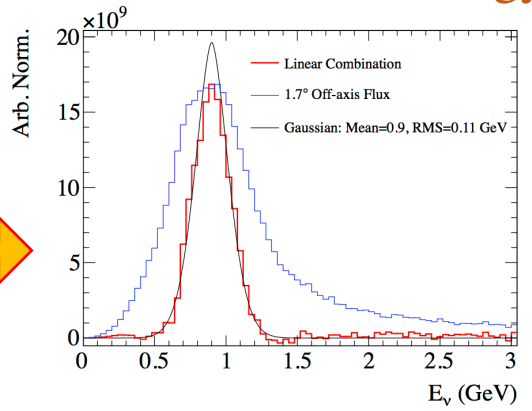




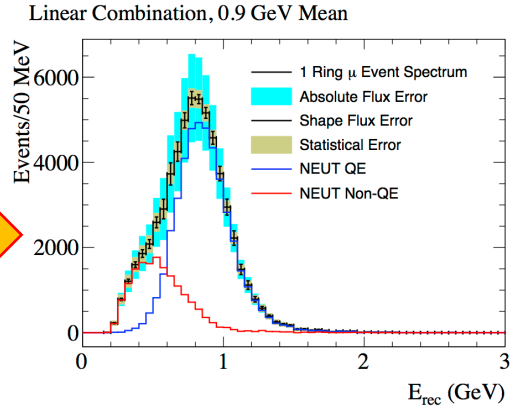
Physics target

- ν-int. measurement by off-axis scanning
- ν_e cross section (3-5% for $\sigma(\nu_e)/\sigma(\nu_\mu), \sigma(\nu_e)/\sigma(\nu_\mu)$)
- NC and intrinsic ν_e BG measurement (3-4%)
- Neutron multiplicity with Gd loading

Linear sum to make monochromatic energy



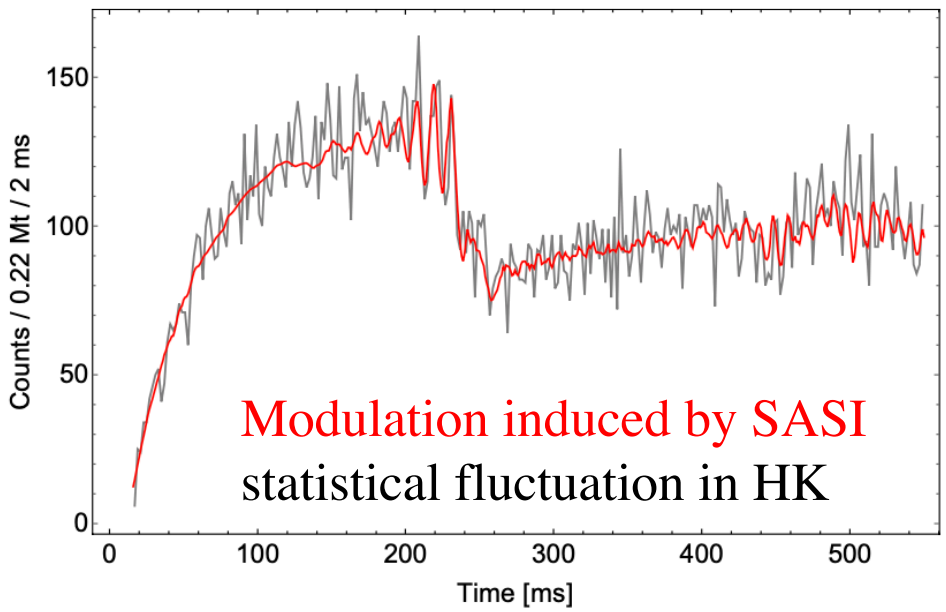
Reconstruction

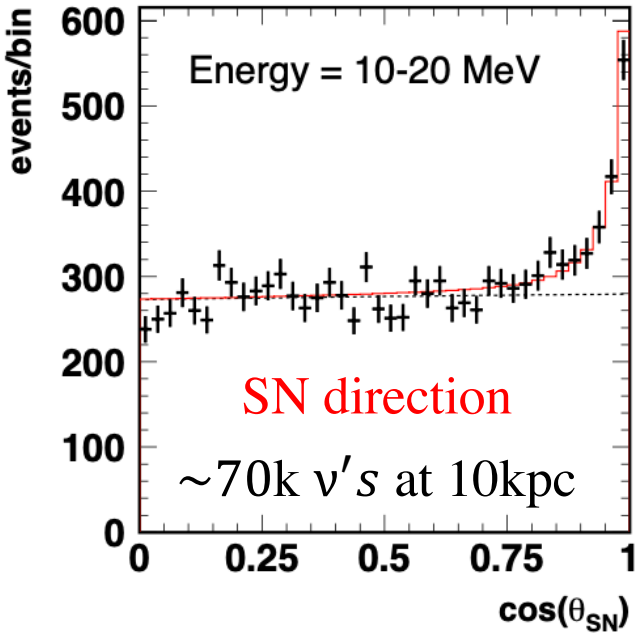


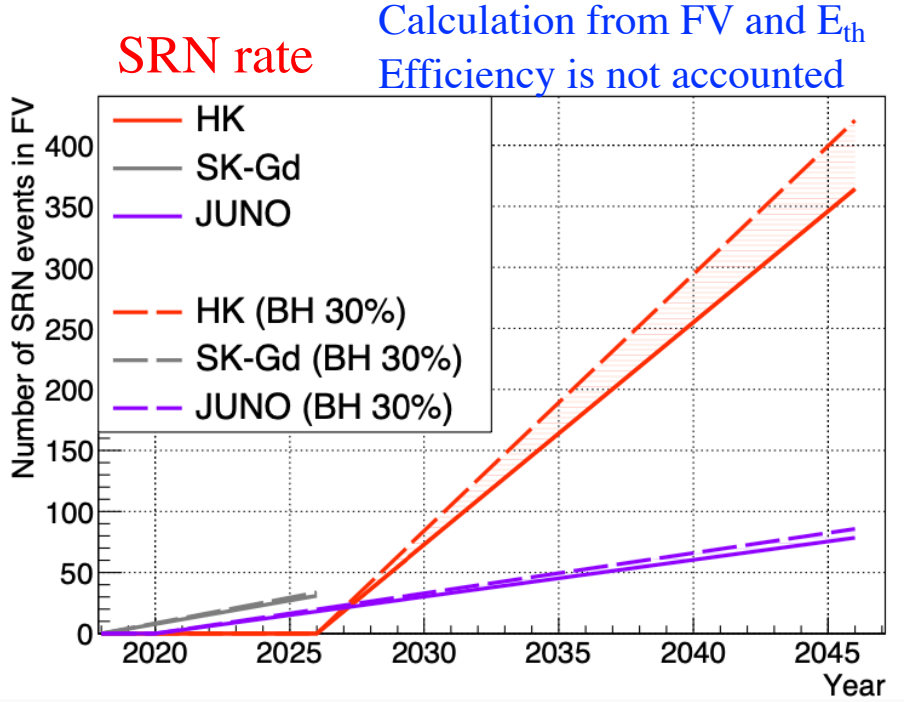
Neutrino astrophysics

Posters
#65: **Radon background model for Hyper-Kamiokande** *(Guillaume Pronost)*
#391: **Supernova Model Discrimination with Hyper-Kamiokande** *(Jost Migenda)*

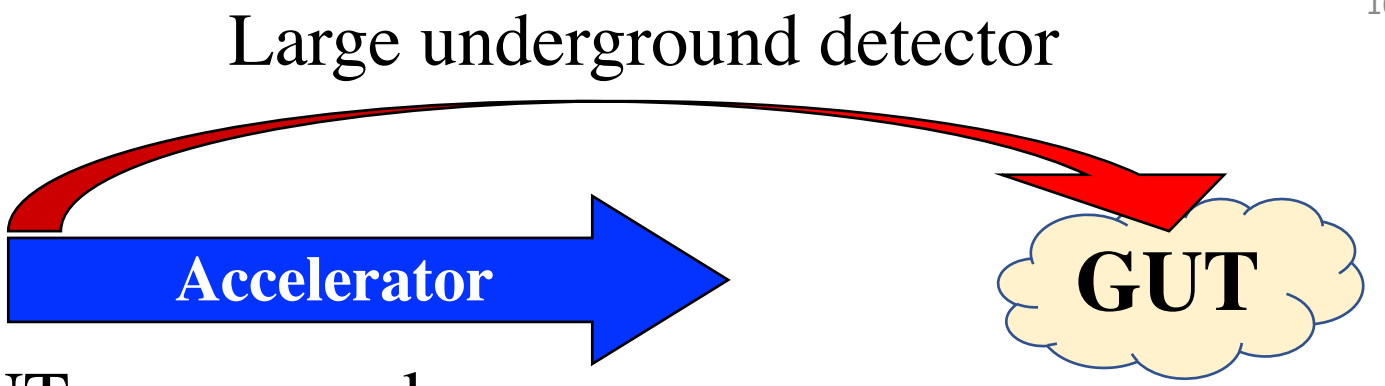
- Observation of ~10 MeV neutrinos with the time, energy and direction
  - Unique role in multi-messenger observation
- Solar neutrinos: up-turn at vacuum-MSW transition region, D/N, hep ν
- Supernova burst: explosion mechanism, BH/NS formation, alert with 1° pointing
- Supernova Relic Neutrino (SRN): stellar collapse, nucleosynthesis and history of the universe





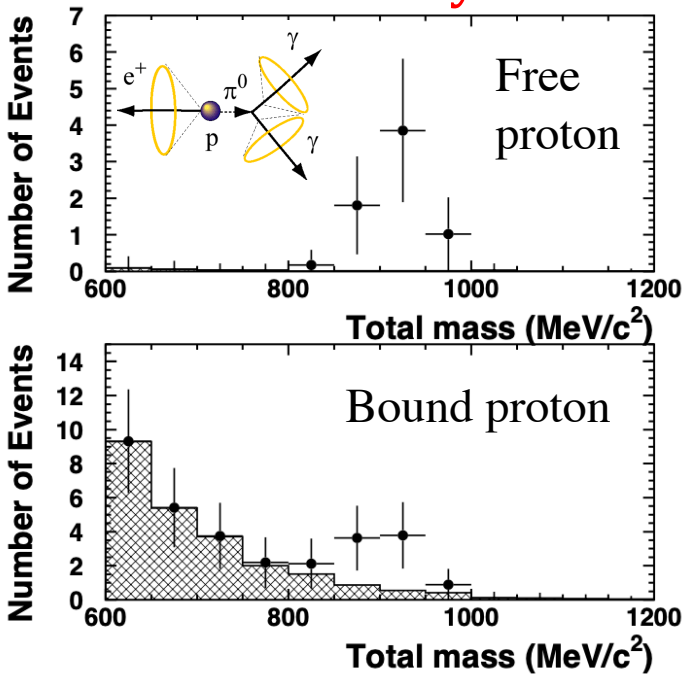


Proton decay search

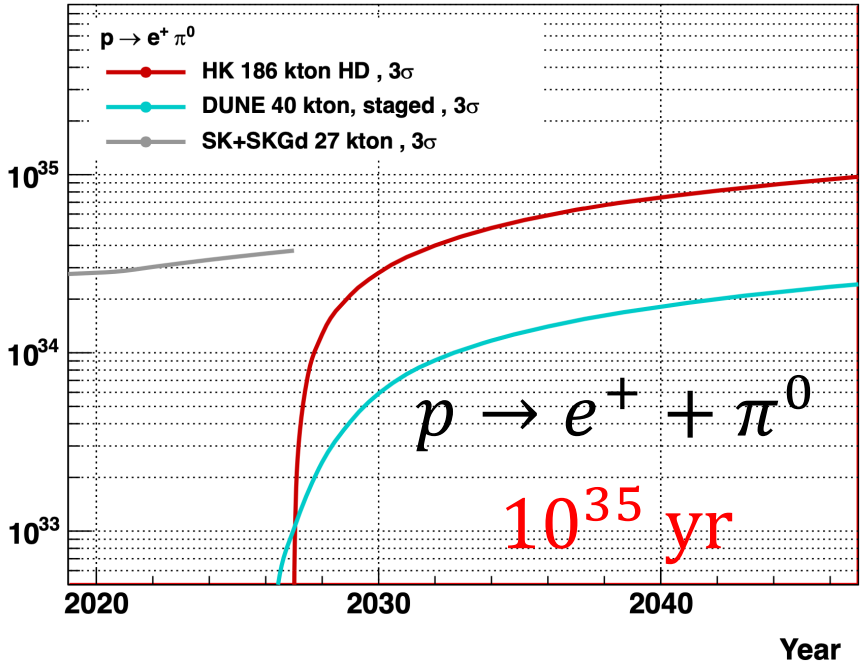


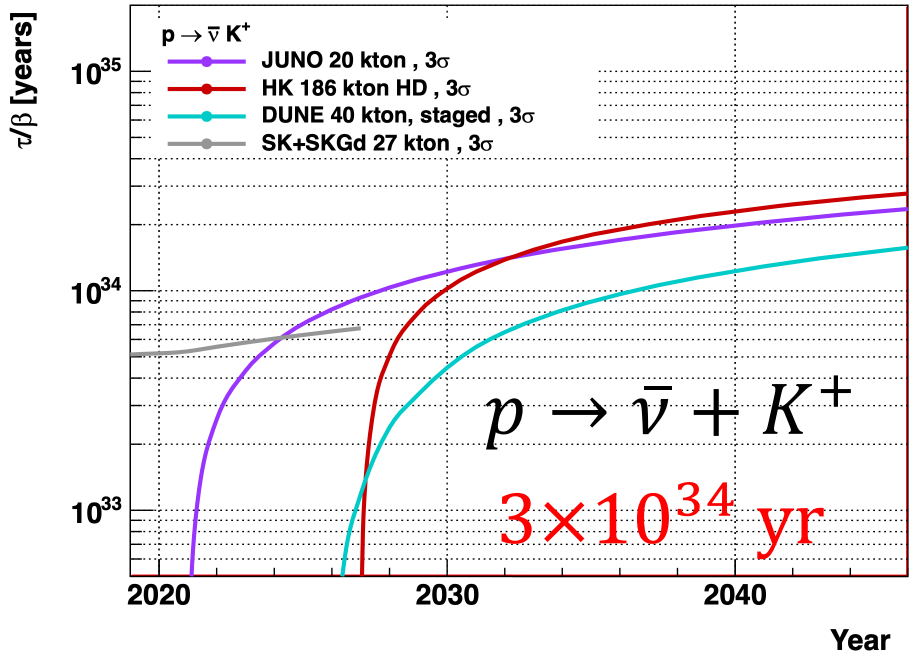
- One possible approach to reach GUT energy scale
- Extend proton decay search by one order of magnitude beyond the current limits

After 10 years of HK
if $\tau = 1.7\times10^{34}$ years …



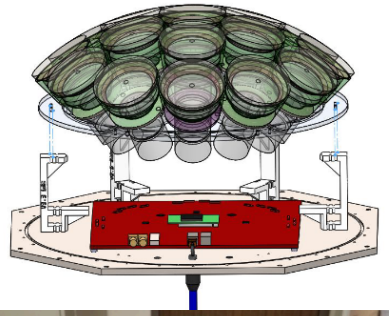
JUNO: J. Phys. G 43 (2016) 030401 (arXiv:1507.05613)
DUNE: FERMILAB-PUB-20-025-ND (arXiv:2002.03005)

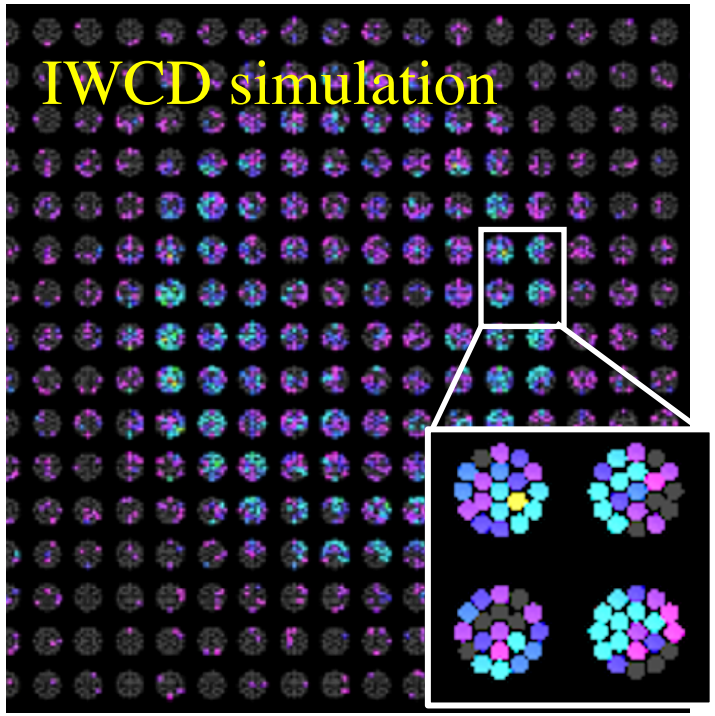




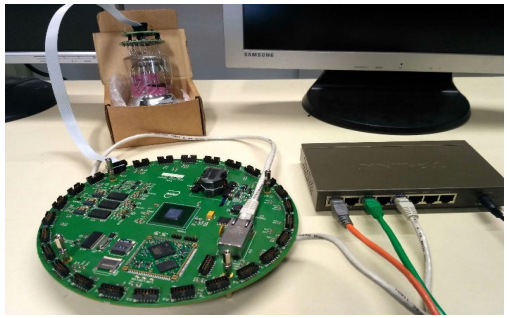
Detector R&D for Hyper-Kamiokande

Multi-PMT module:
(ref. KM3NeT)
High resolution Cherenkov ring imaging essential for IWCD
Consider to use for part of HK



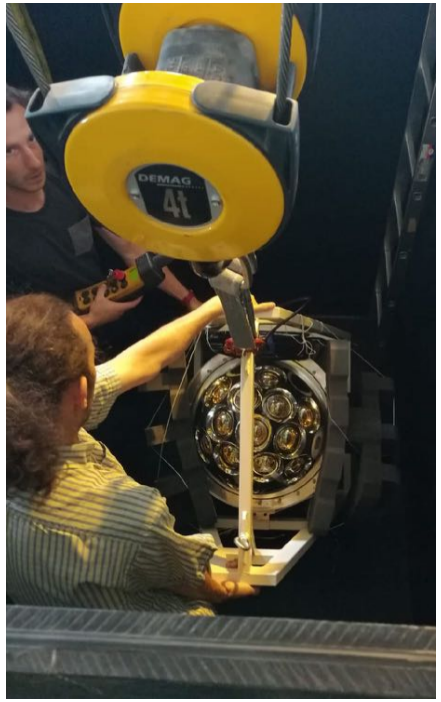


Prototype at TRIUMF

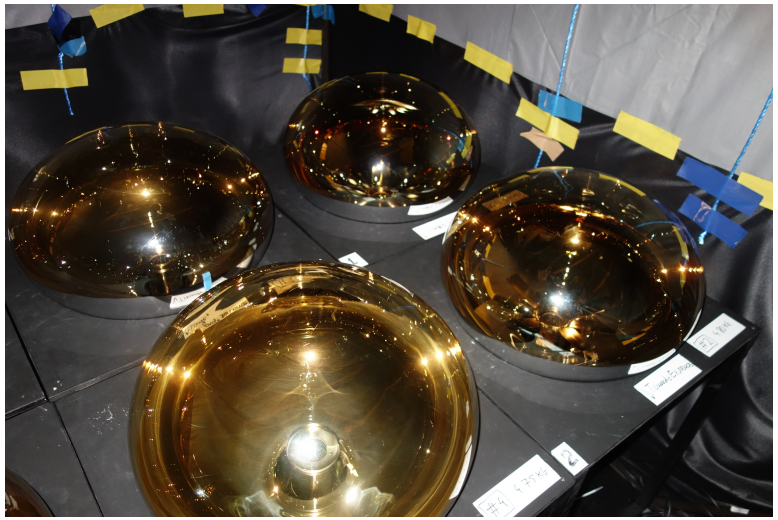


Electronics at INFN

20-inch MCP PMT:
Test in dark room



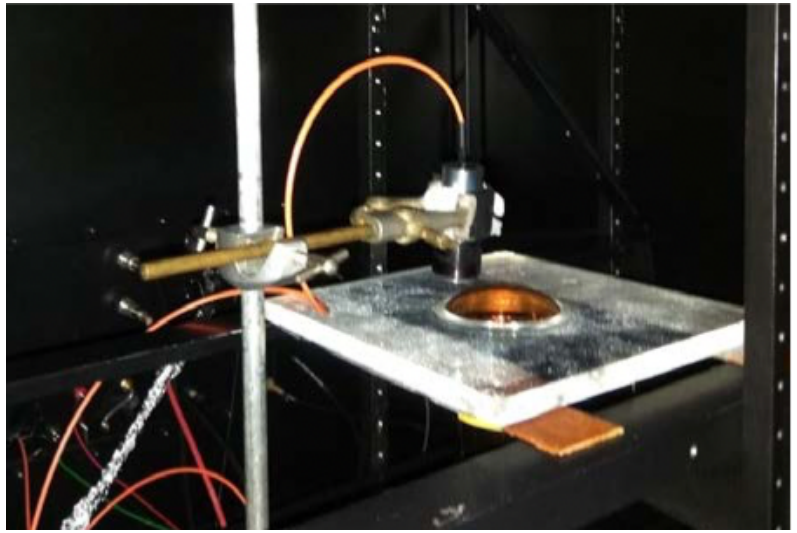
mPMT in Memphyno water tank in France

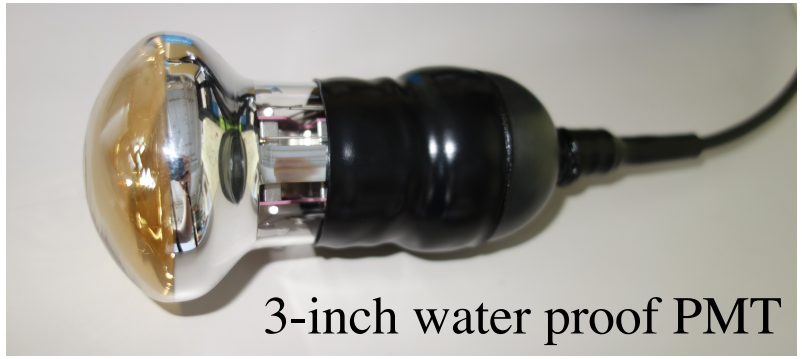


Box&Line PMT in Super-K

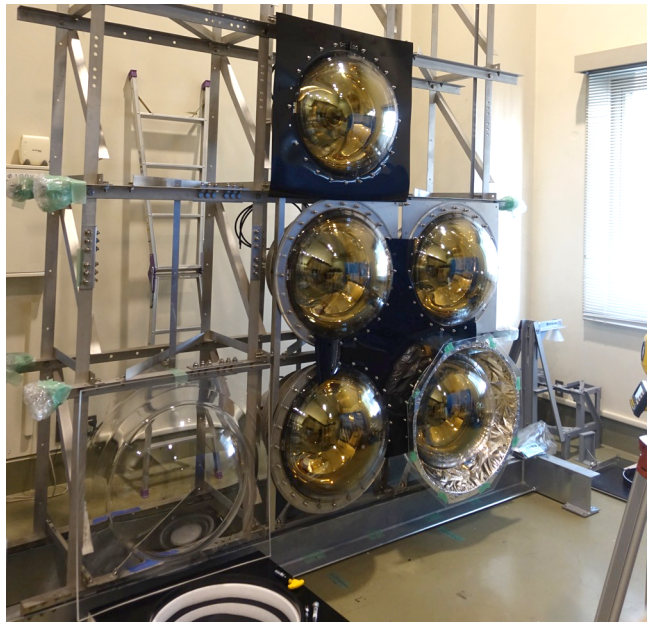
Detector R&D for Hyper-Kamiokande

Outer detector:
PMT + WLS plate (UK)



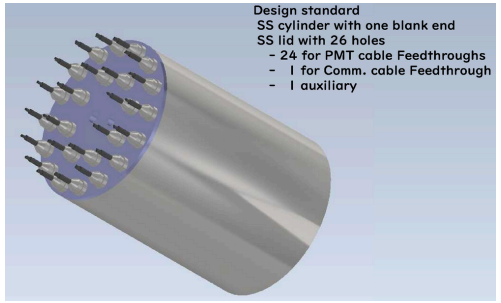


ID mockup at ICRR

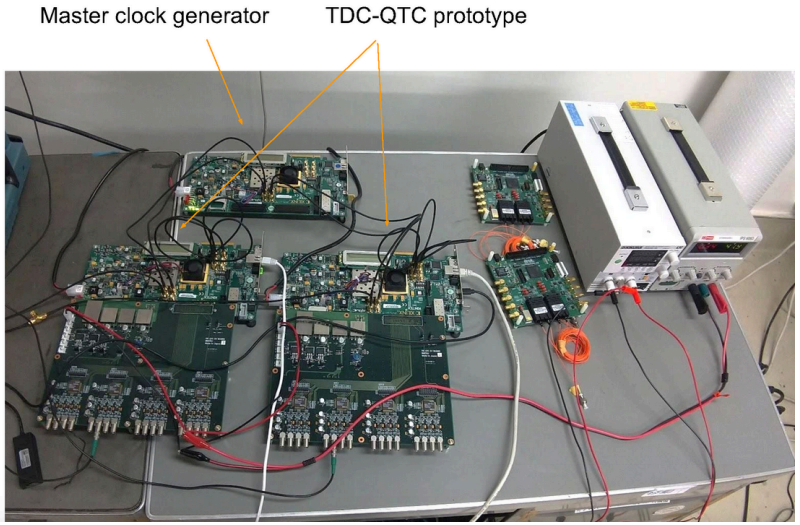


PMT cover
in Spain

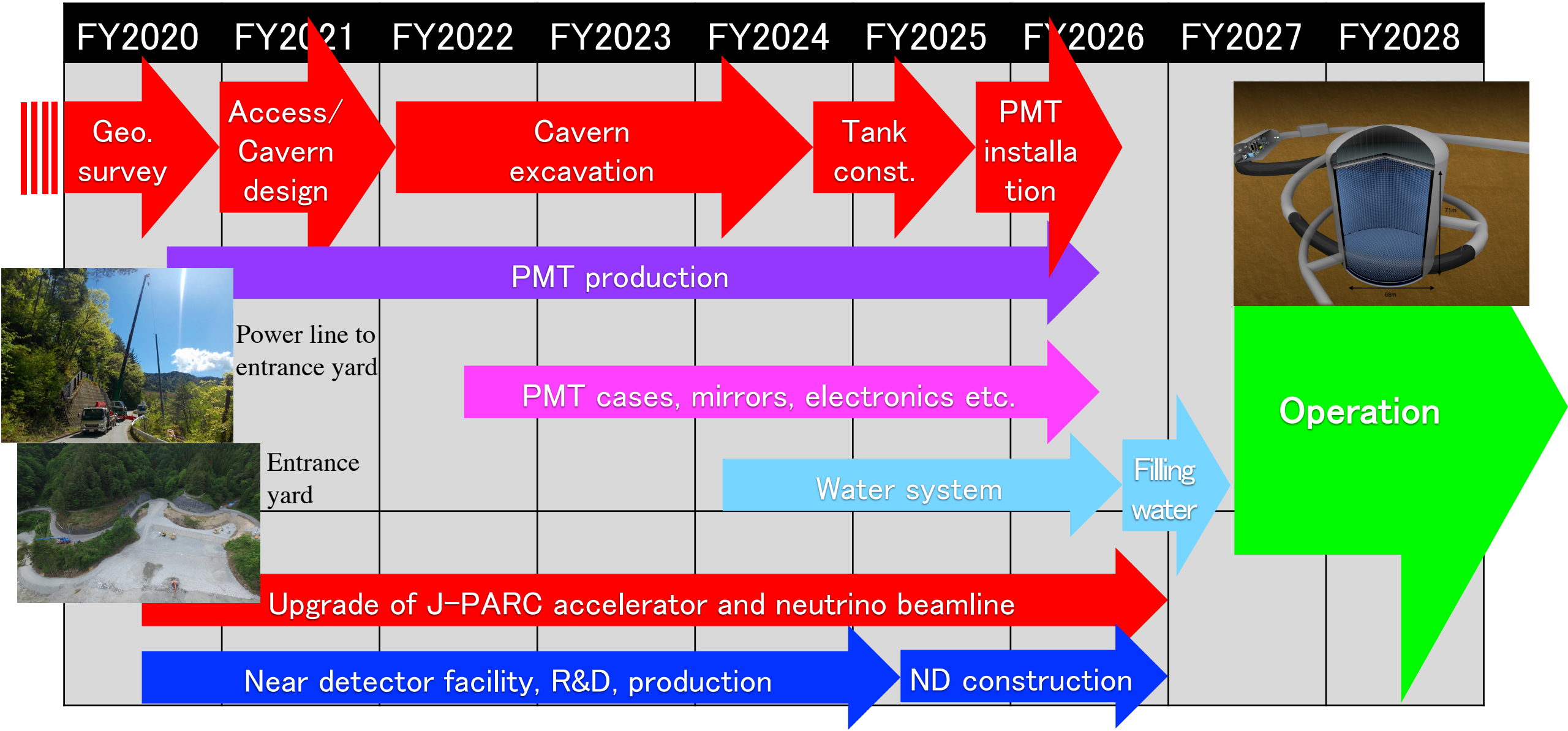
Underwater electronics:
Case design and feedthrough



Sync and clock system
test bench at TokyoTech



Hyper-Kamiokande schedule



Summary

- Hyper-Kamiokande is the next generation underground water Cherenkov detector in Kamioka aiming for groundbreaking physics:
  - Search for proton decay by one order of magnitude beyond the current limits
  - Reveal full picture of neutrino oscillations including CP violation and mass ordering
    - Unprecedented high statistic neutrino data with upgraded J-PARC neutrino beam
  - Unique contribution to astrophysics by the neutrino observations (solar, SN burst, SRN)
- Hyper-Kamiokande is officially approved in Japan
  - Hyper-Kamiokande is under construction and will begin operation in 2027
  - International R&D is actively ongoing to improve the physics potential
    - Near detectors, photo-sensors and covers, electronics, outer detector etc.
  - New collaborators are welcome to contribute to the detectors and the pioneering physics!