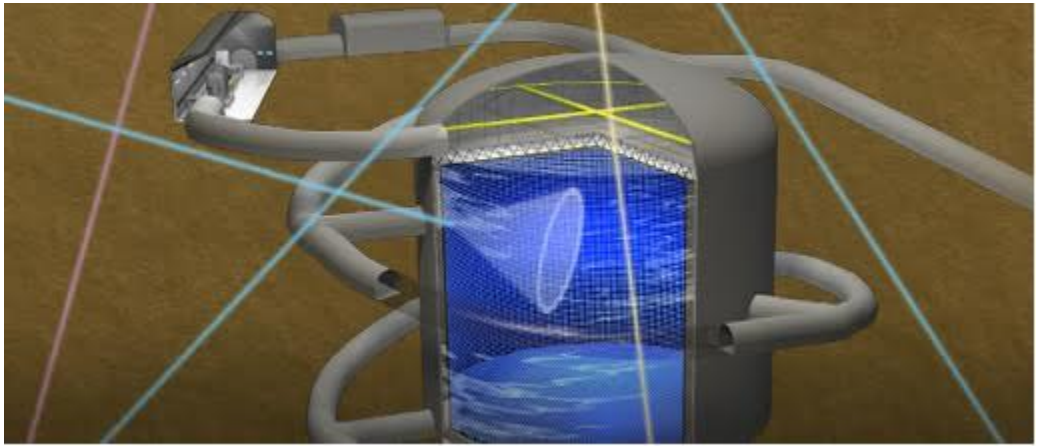
Hyper-Kamiokande

http://hyperk.org



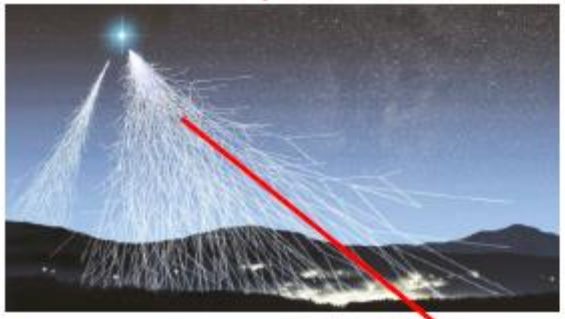
Status of Hyper-Kamiokande T2HK

Alessandro Bravar
on behalf of the HK Collaboration

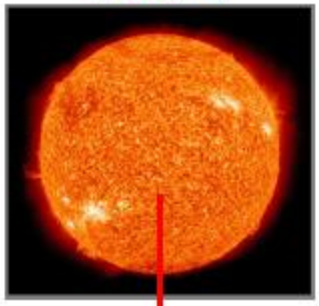
TAU2021
Oct 01, 2021

Hyper-K Physics Overview

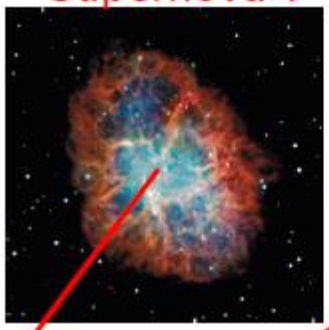
Atmospheric ν



Solar ν

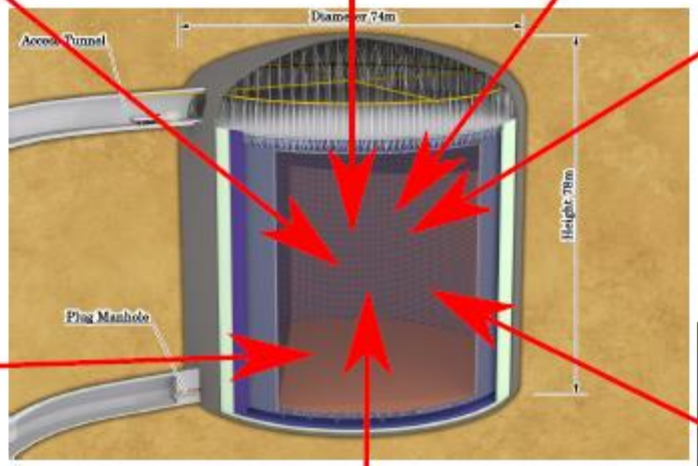


Supernova ν

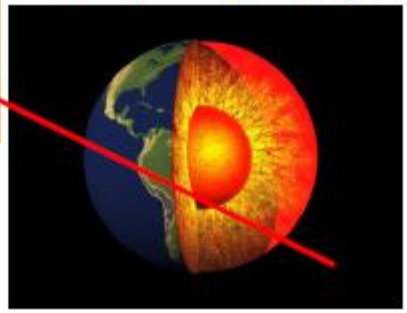


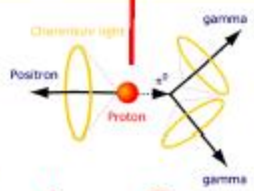
WIMP $\chi\chi$ -> νν

Beam ν



ν Tomography





Nucleon Decay

Broad Science Program with Hyper-K

Neutrino oscillation physics
- comprehensive study with beam and atmospheric neutrinos
  - determination of neutrino mass hierarchy
  - determination of θ_{23} octant
  - measurement of CP Violation in leptonic sector
  - reveal exotic scenarios

Search for nucleon decay
- possible discovery with ~10 × SK sensitivity
- all visible modes including $p \rightarrow e^+ \pi^0$ and $p \rightarrow \bar{\nu} K^+$
- reach 10^{35} years sensitivity

+ unexpected (unknown)

Solar neutrino physics
- precision measurement of Δm^2_{21}
- measurement of energy spectrum upturn
- discovery & measurement of hep neutrinos

Neutrino Astrophysics
- high statistics measurement of SN burst neutrinos
- detection and study of relic SN neutrinos
- indirect Dark Matter search from Galactic Core, Sun, Earth

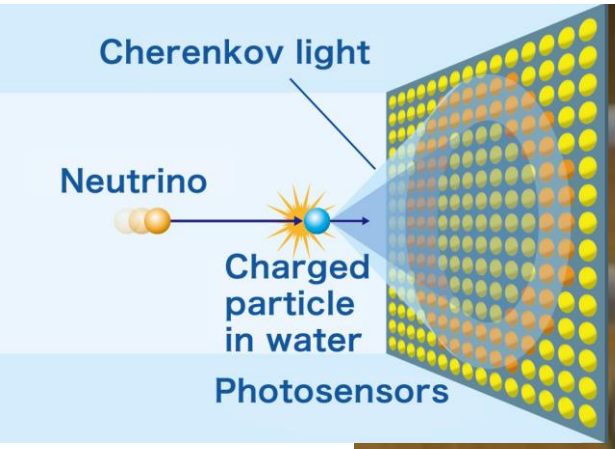
Geophysics ("neutrinography" of Earth's interior)

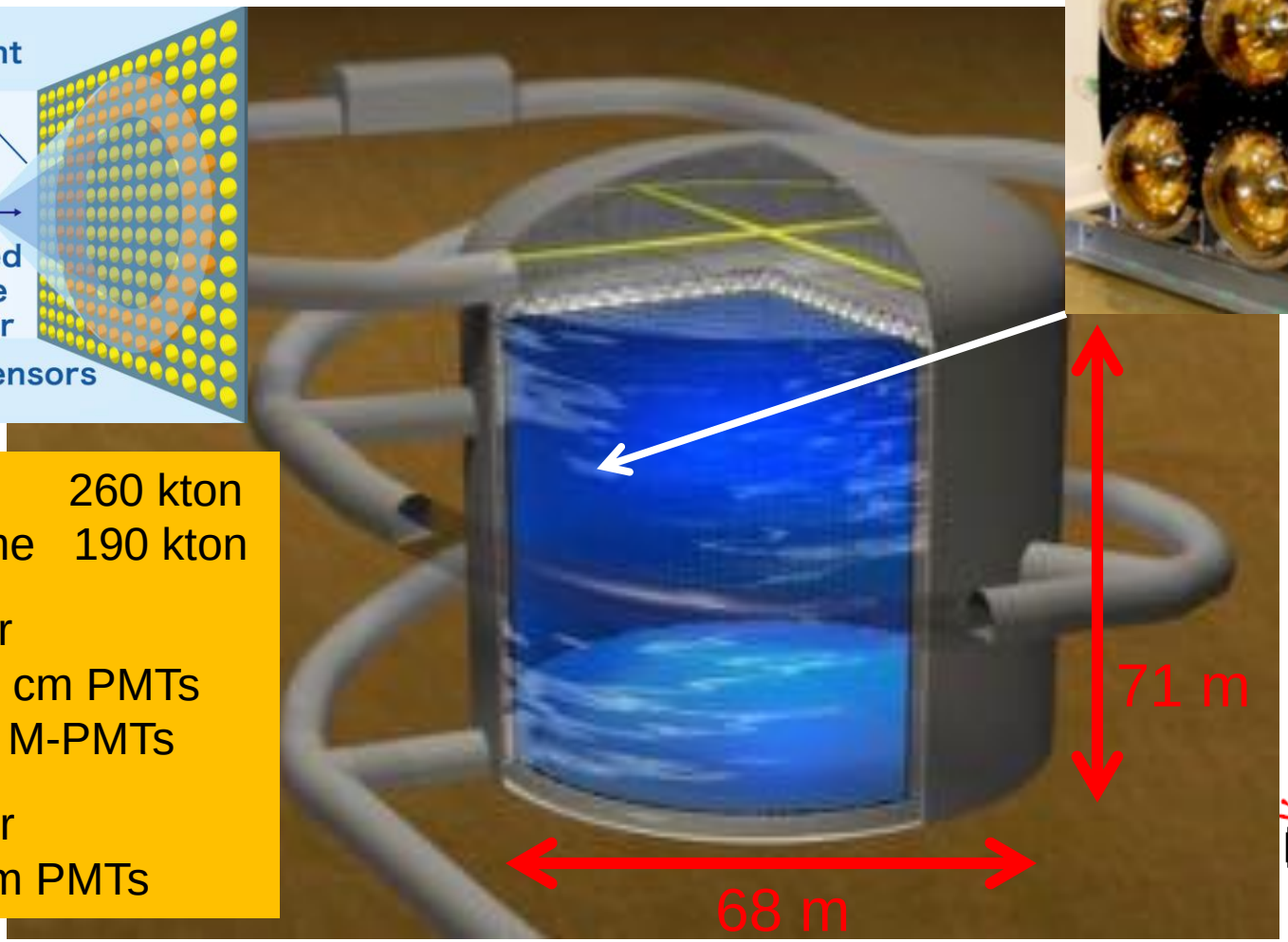
The Hyper-Kamiokande Detector

Large Water Cherenkov Detector

Larger mass for more statistics

Better sensitivity by more photons with improved sensors





total volume 260 kton
fiducial volume 190 kton

inner detector
- 20,000 50 cm PMTs
- few 1,000 M-PMTs

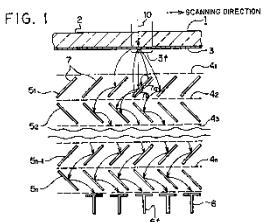
outer detector
- 6,700 8 cm PMTs

Upgraded Photo-Sensors

Super-K PMT

used in SK for 20 yrs

high QE photocathode

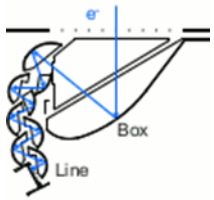


Venetian Blind

HQE SK PMT

under validation

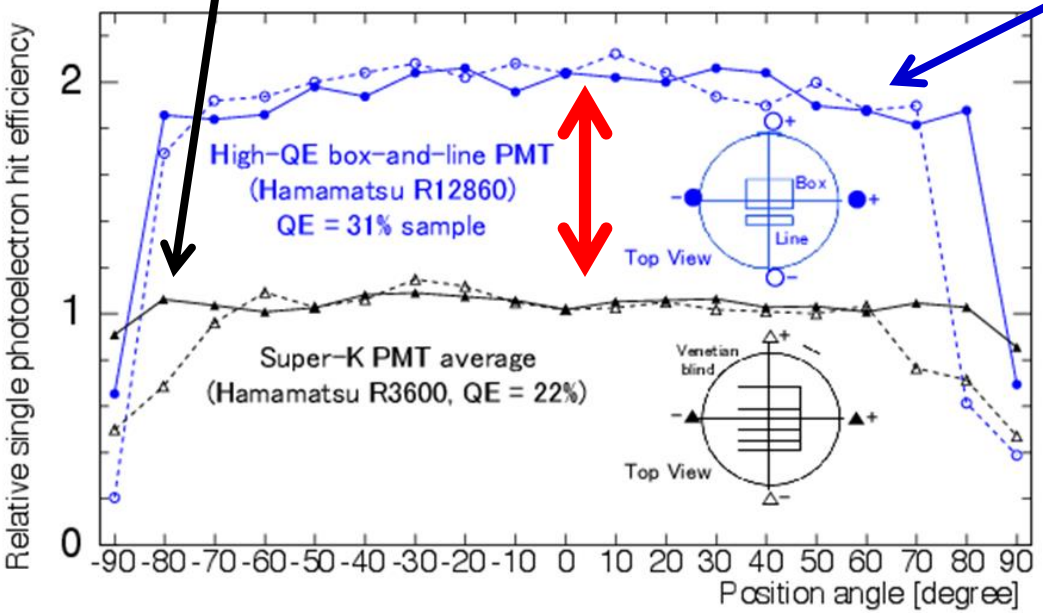
dynode improvement



Box-and-Line Dynode

50 cm HQE Box&Line PMT

under validation



Enhanced performance

Photo Detection Efficiency 2 × bigger

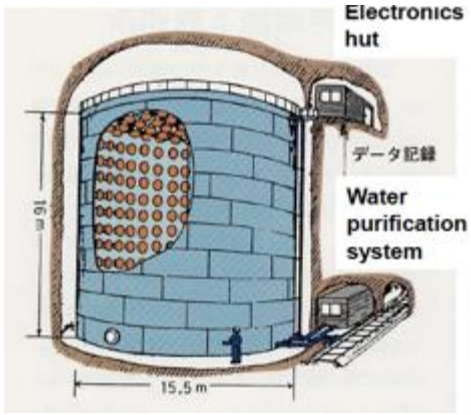
Timing resolution 2 × as good

Increased Pressure tolerance × 2

- enhance $p \rightarrow \bar{\nu} K^+$ signal
- solar ν lower threshold
- neutron capture signature
  ($n + p \rightarrow d + \gamma$ - 2.2MeV γ)

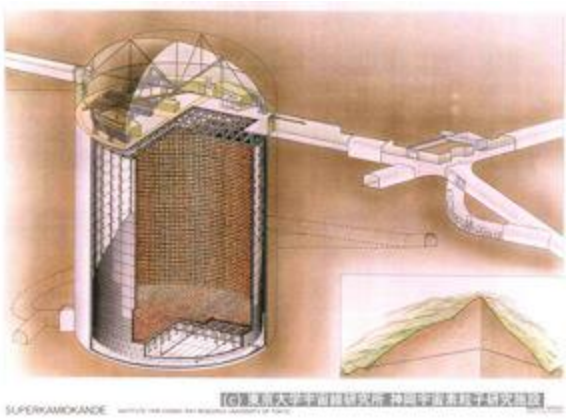
3 Generations of Kamioka Detectors

Kamiokande
(1983 – 1996)



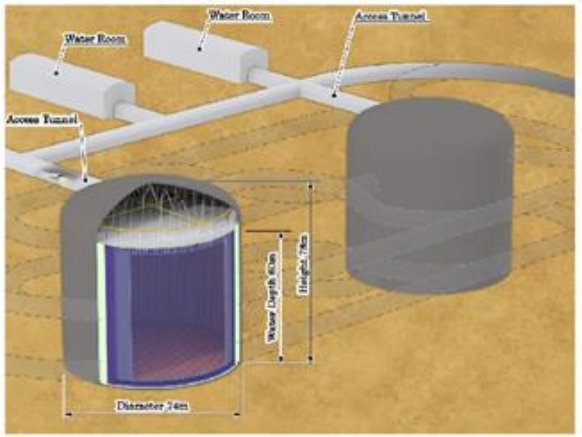
3 kton
20% coverage
with 50 cm PMT

Super-Kamiokande
(1996 –)



50 kton
40% coverage
with 50 cm PMT

Hyper-Kamiokande
(2027 –)



260 kton
20% coverage with
high-QE 50 cm PMT

Observation of SN1987A

Discovery of
ν oscillations

?

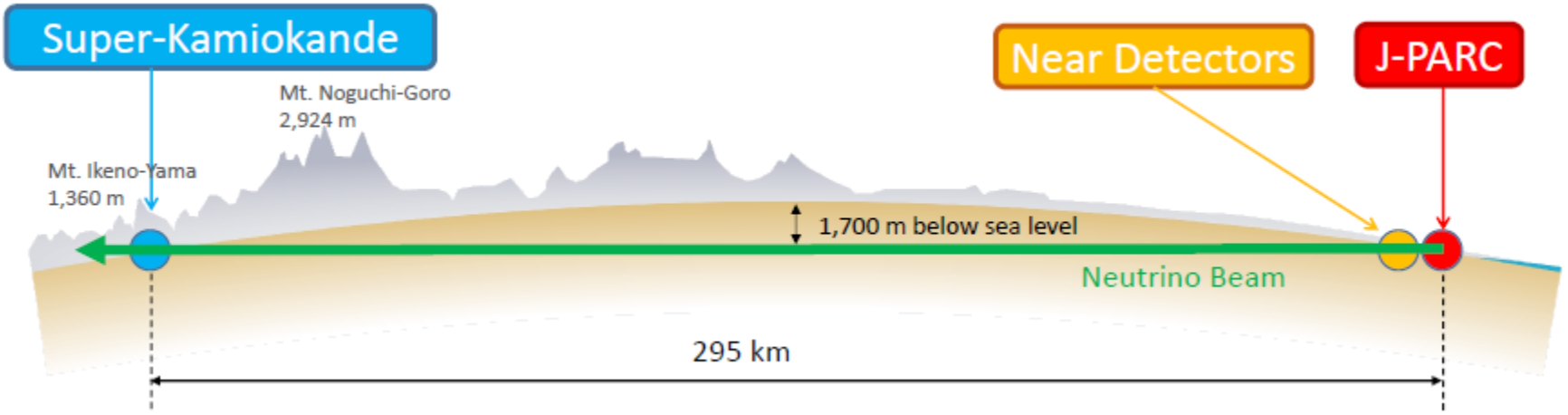
Prepare for the unknown

The Hyper-K Collaboration

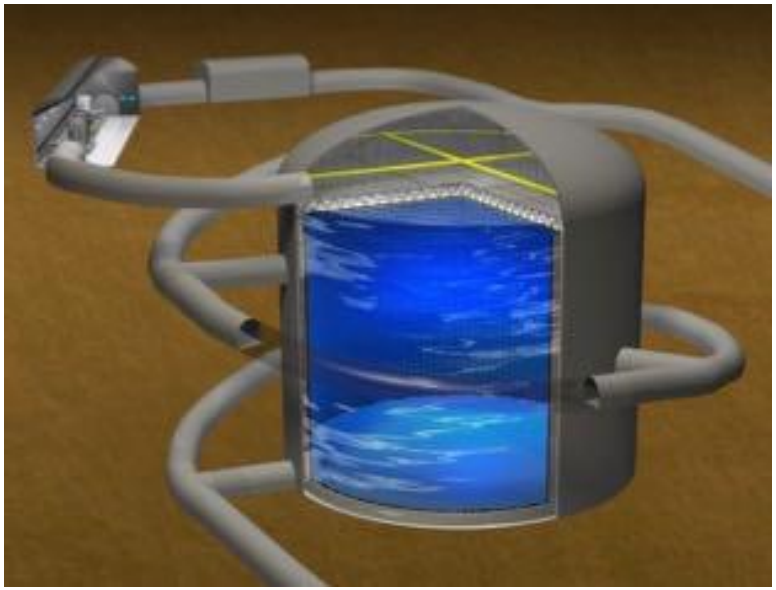
January 2015

19 countries
93 institutes
~450 members
(and growing)

From J-PARC to Kamioka (T2HK)



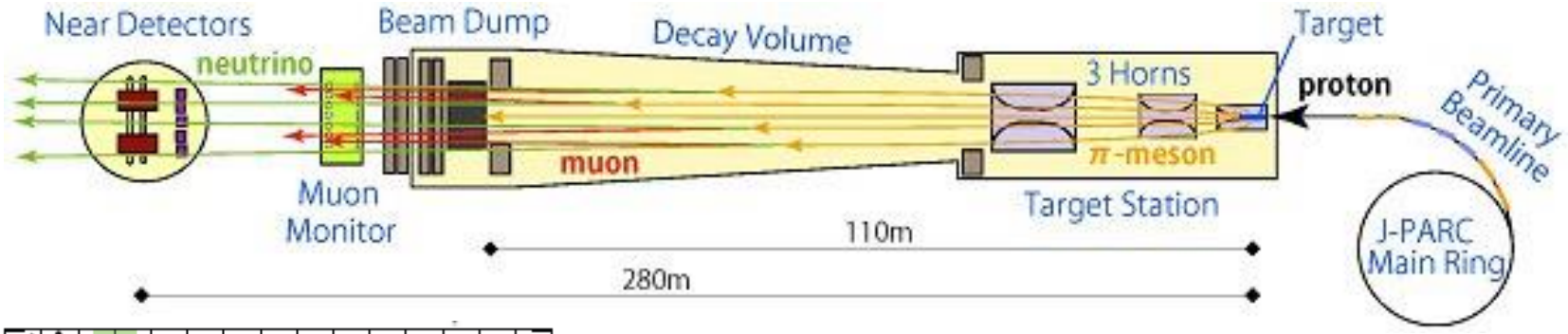
260 kton Water Cherenkov Detector

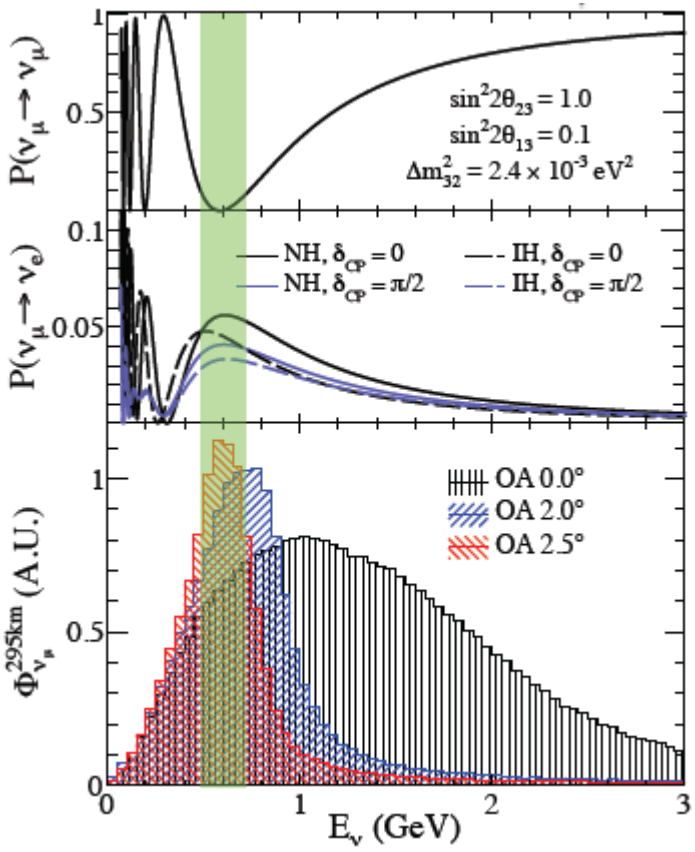


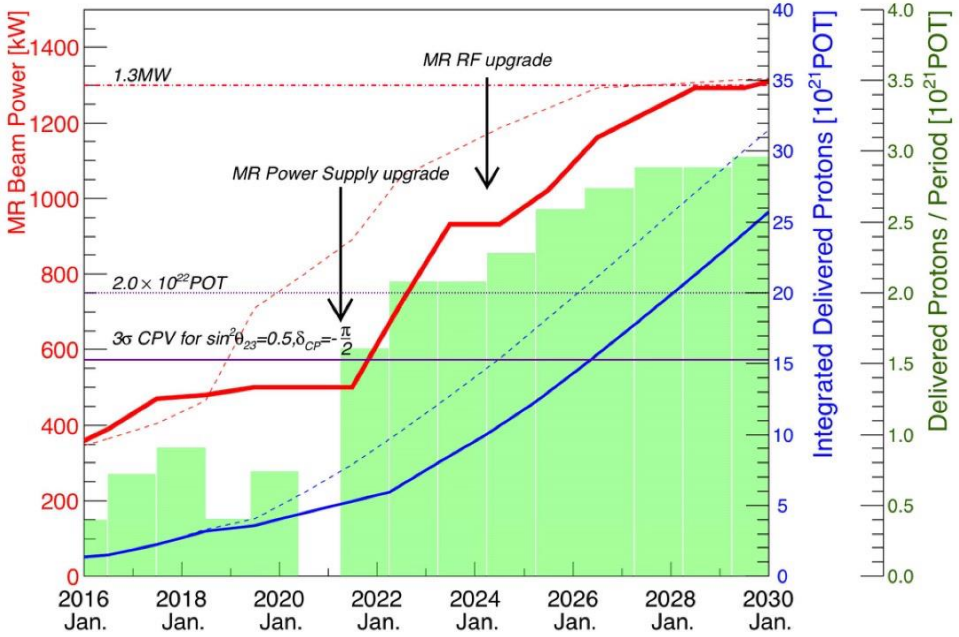
+

Upgraded J-PARC neutrino beam
New / upgraded near detectors

Beamline Upgrade







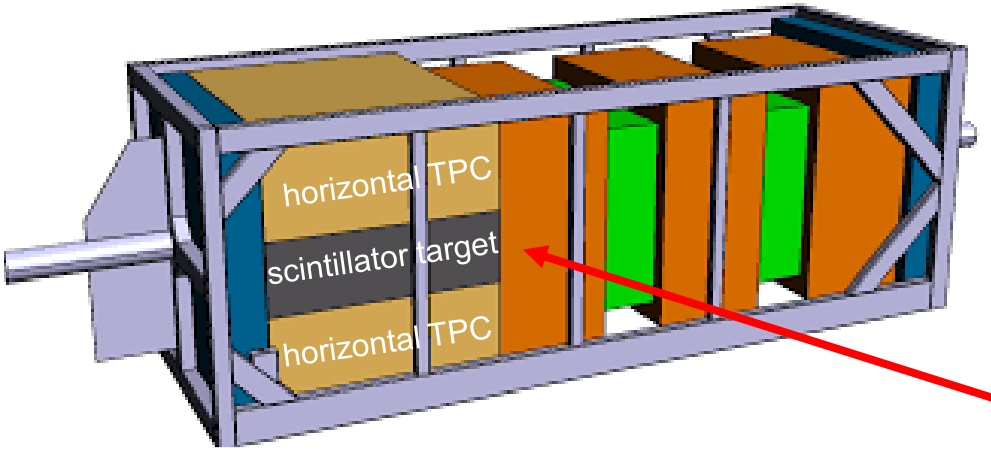
1.3 MW by ~2028

repetition cycle from 2.48 s to 1.3 s

protons 2.4×10^{14} / spill to 3.2×10^{14} / spill

The Near Detectors @ J-PARC

upgraded ND280 Near Detector



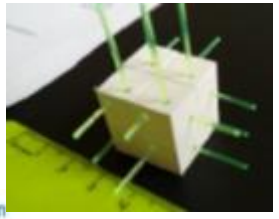
designed to address ν – Nucleus interactions and modeling

enlarge phase space (4π coverage)

efficiency for short hadron tracks with proton reconstruction

improve electron neutrino selection

new: horizontal TPCs
scintillator target
ToF



Intermediate Water Cherenkov

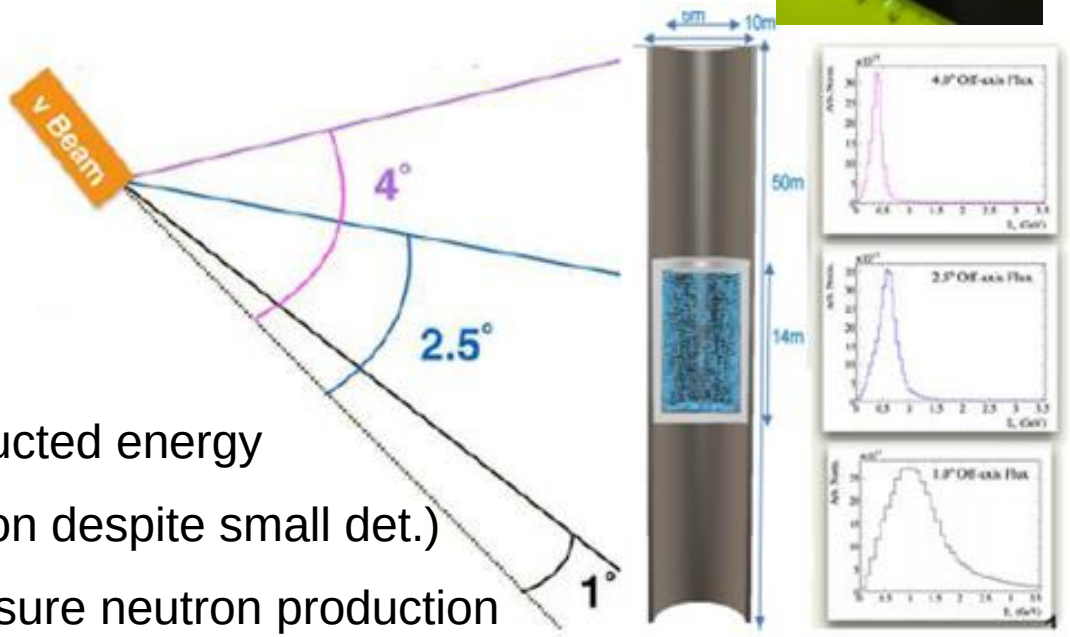
~600 ton water Cherenkov located at ~1 km from ν source

off-axis angle spanning orientation vary ν peak energy

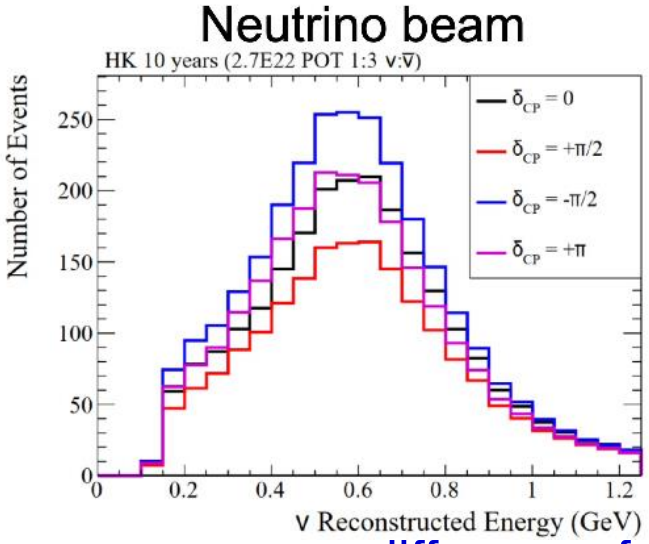
probe neutrino energy vs. reconstructed energy

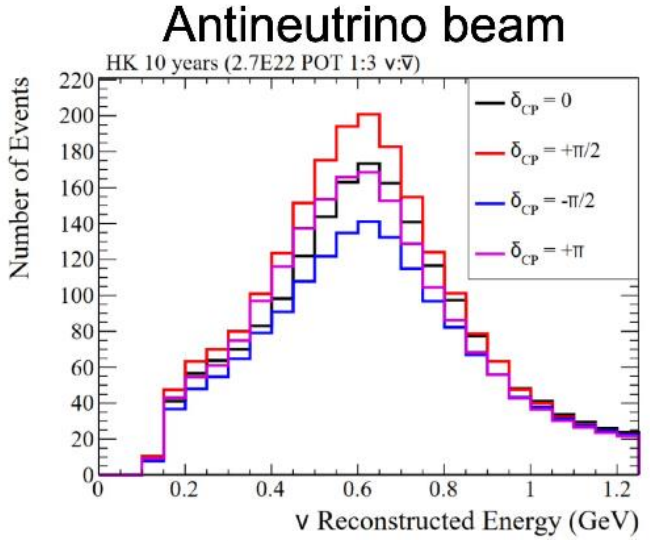
multi-PMT units (good reconstruction despite small det.)

potential to loading with Gd to measure neutron production

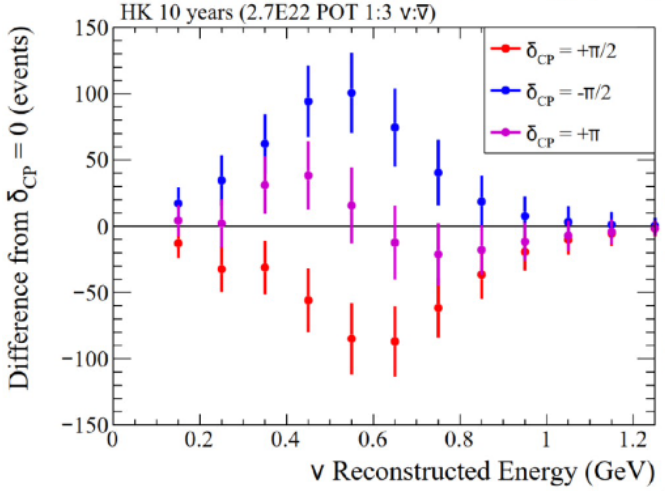


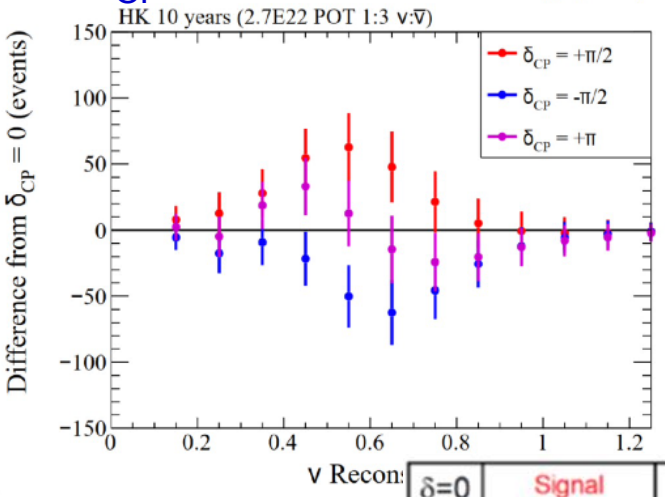
Beam Events in T2HK: ν_e appearance





difference from $\delta_{CP} = 0$





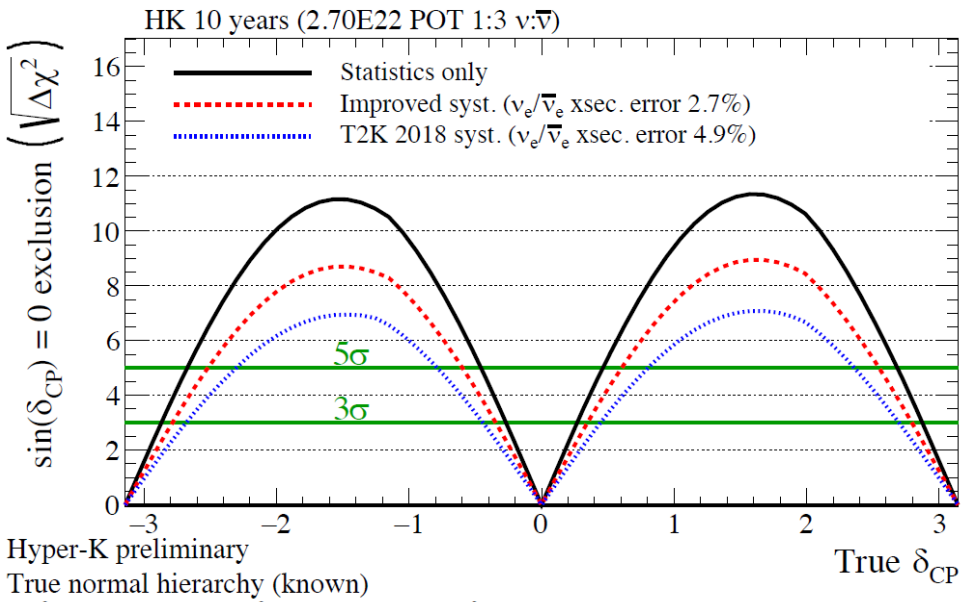
10 years data taking
190 kton fiducial $\times$ 1.3 MW

δ=0	Signal ($\nu_\mu \rightarrow \nu_e$ CC)	Wrong sign appearance	$\nu_\mu, \bar{\nu}_\mu$ CC	Beam $\nu_e, \bar{\nu}_e$ contamination	NC
ν beam	2300	21	10	362	188
$\bar{\nu}$ beam	1656	289	6	444	274

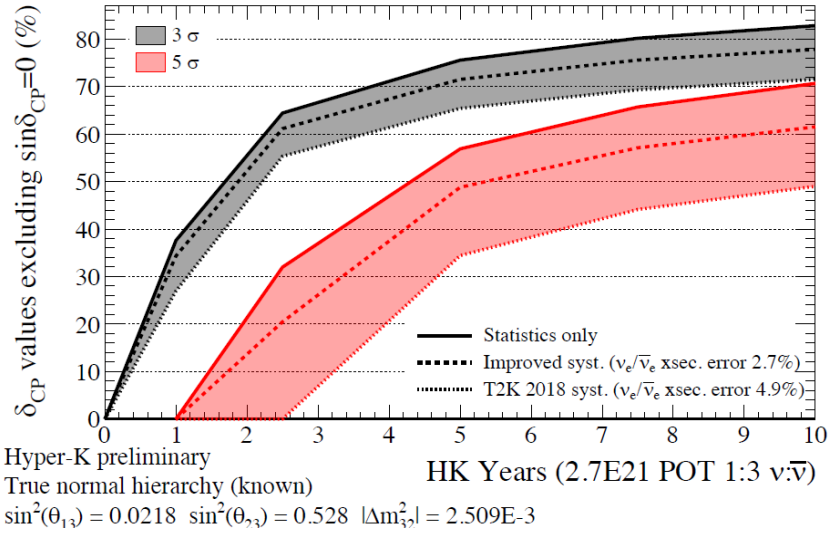
T2HK Sensitivity to δ_{CP}

assumes normal ordering known

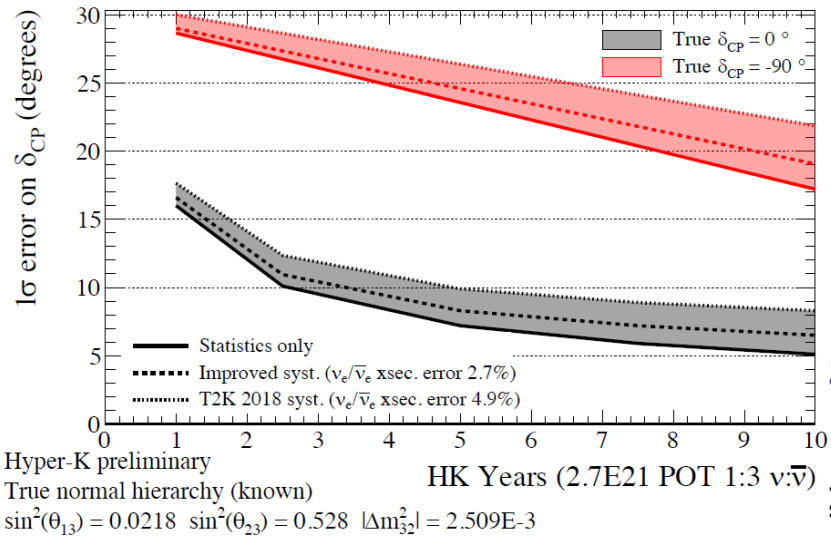
significance to exclude δ_{CP} = 0



fraction of δ_{CP} values for which $\sin(\delta_{CP}) = 0$ can be excluded



accuracy for 2 different δ_{CP} values



sin δ_{CP} = 0 exclusion:

- ~8-σ significance if $\delta_{CP} = \pm 90°$
- ~6-σ significance if $\delta_{CP} = \pm 45°$
- ~80% coverage of δ_{CP} parameter space

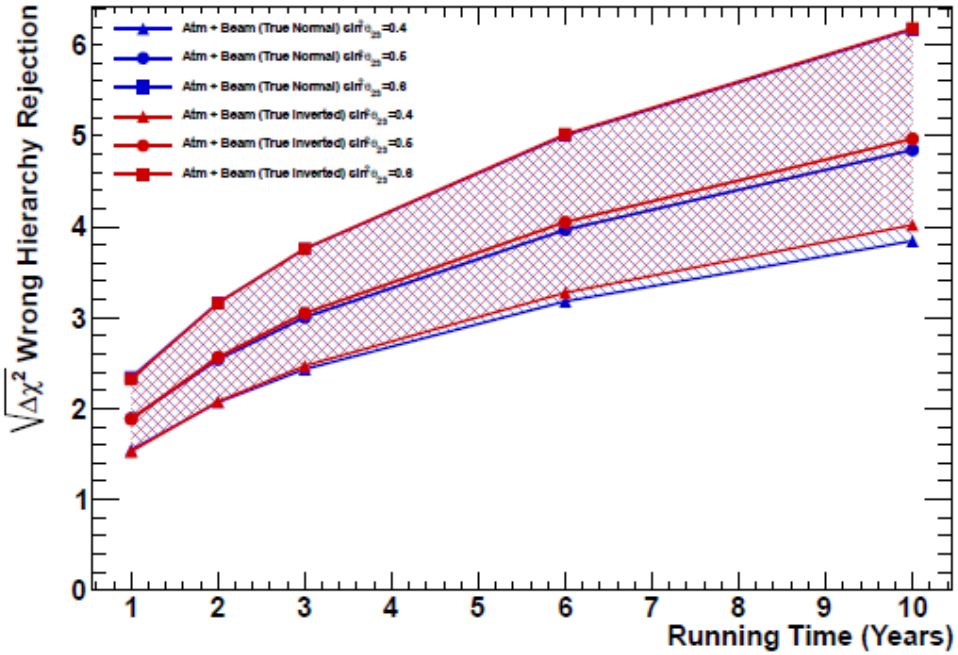
Mass Hierarchy

295 km baseline does not produce significant matter effects

atmospheric neutrinos are sensitive to matter effects in Earth

beam ν + atmospheric $\nu \rightarrow$ sensitivity to mass ordering

atmospheric neutrinos allow to break possible degeneracies between MH and δ_{CP} when MH is unknown

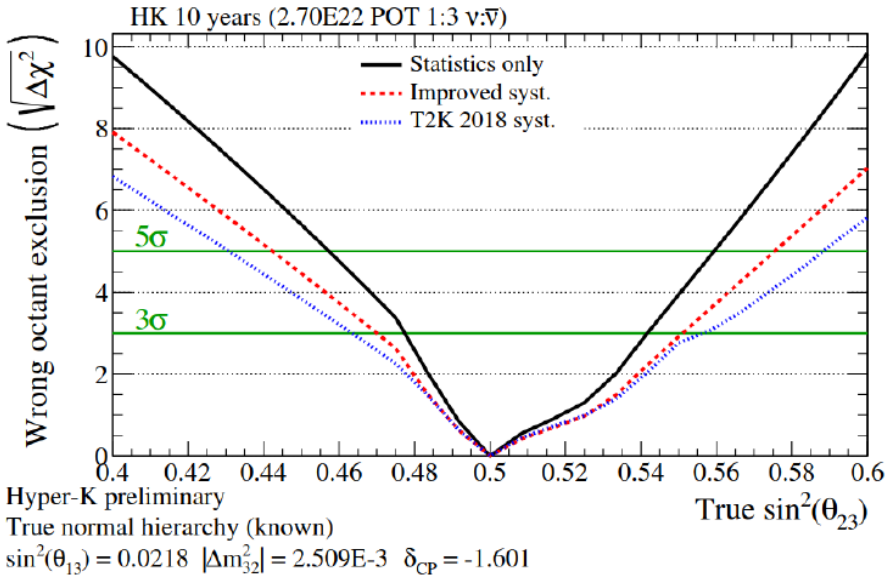


combining the two

>3σ ability to reject wrong MH

5σ for larger values of $\sin^2 \theta_{23}$

sensitivity to θ_{23} octant



More Physics with Atmospheric ν

Atmospheric ν:
- neutrinos with various energy, flight length, and flavor

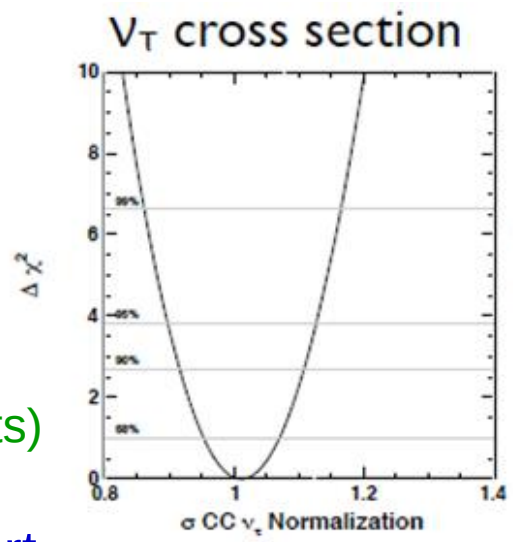
ν_τ cross section measurement

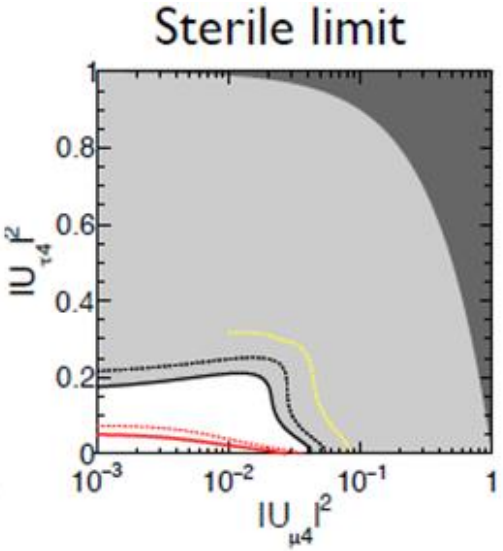
Sterile neutrinos

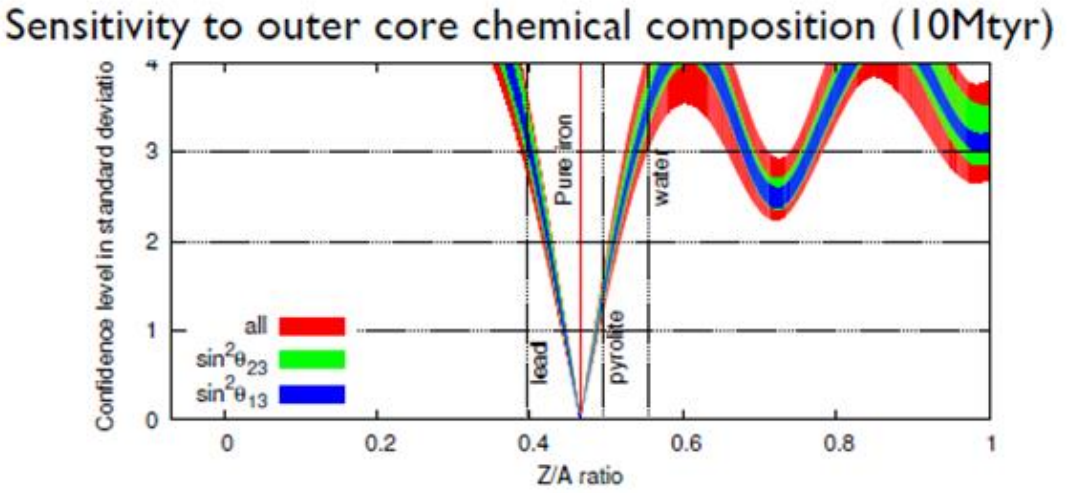
Lorentz violation studies
(3 – 4 × stronger than current SK limits)

dark matter annihilation into SM part.
(3 – 5 × stronger than current SK limits)

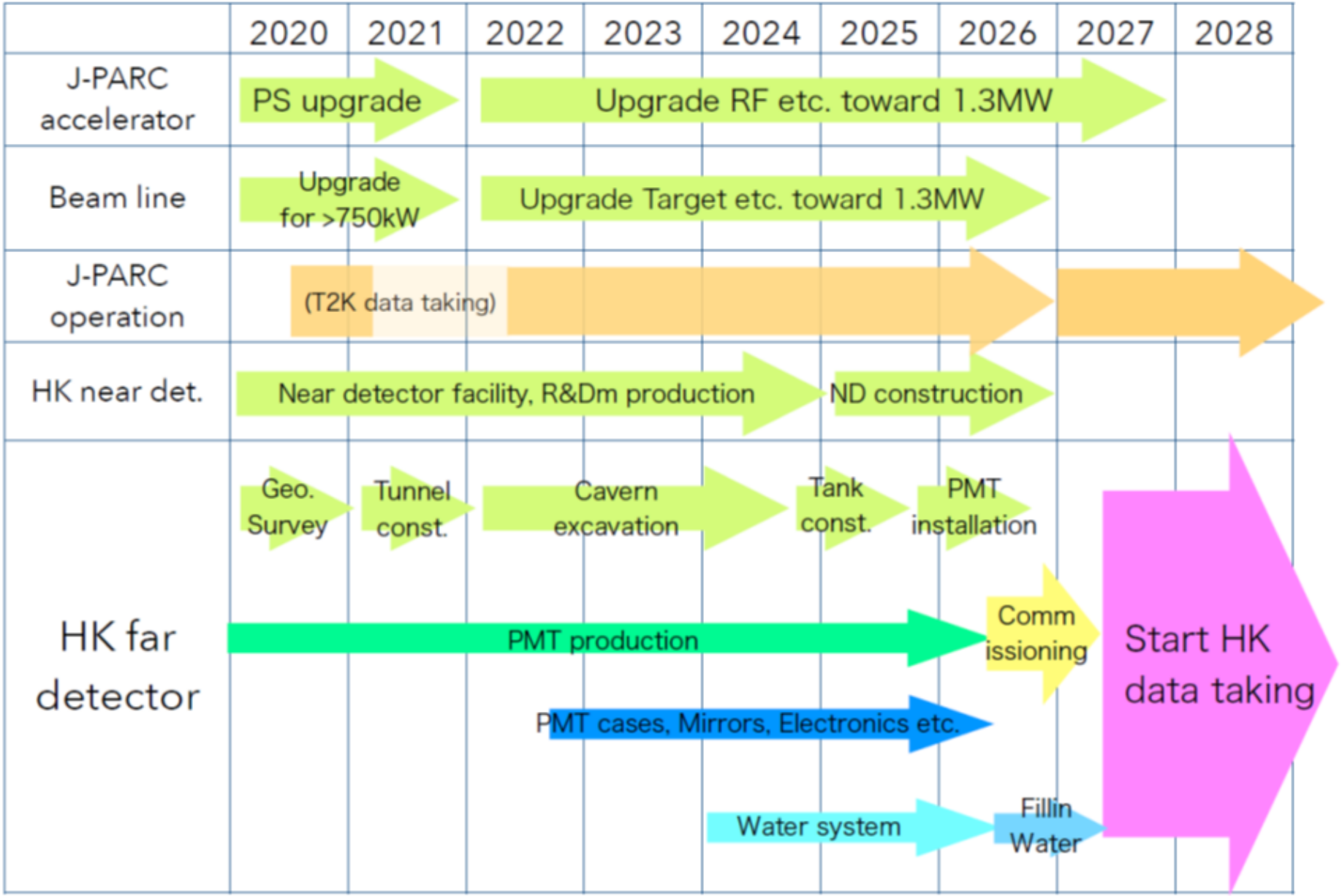
Geophysics
- chemical composition of Earth's outer core using matter effect







Hyper-K Schedule



Summary

A new adventure in ν Physics to start

Hyper-K next generation neutrino experiment, 190 kton fiducial volume
Hyper-K will address major open questions in science

- Neutrino CP violation and mass ordering
- Proton decay
- Astrophysics (SN neutrinos)
- …..

Construction of Hyper-K water Cherenkov is ongoing (started in 2020)

- J-PARC beam upgrade to 1.3 MW
- Upgrade Near Detectors
- Intermediate Water Cherenkov Detector

Start to take data in 2027