Hyper-Kamiokande計画
現状と展望

田中秀和

ICRR, University of Tokyo

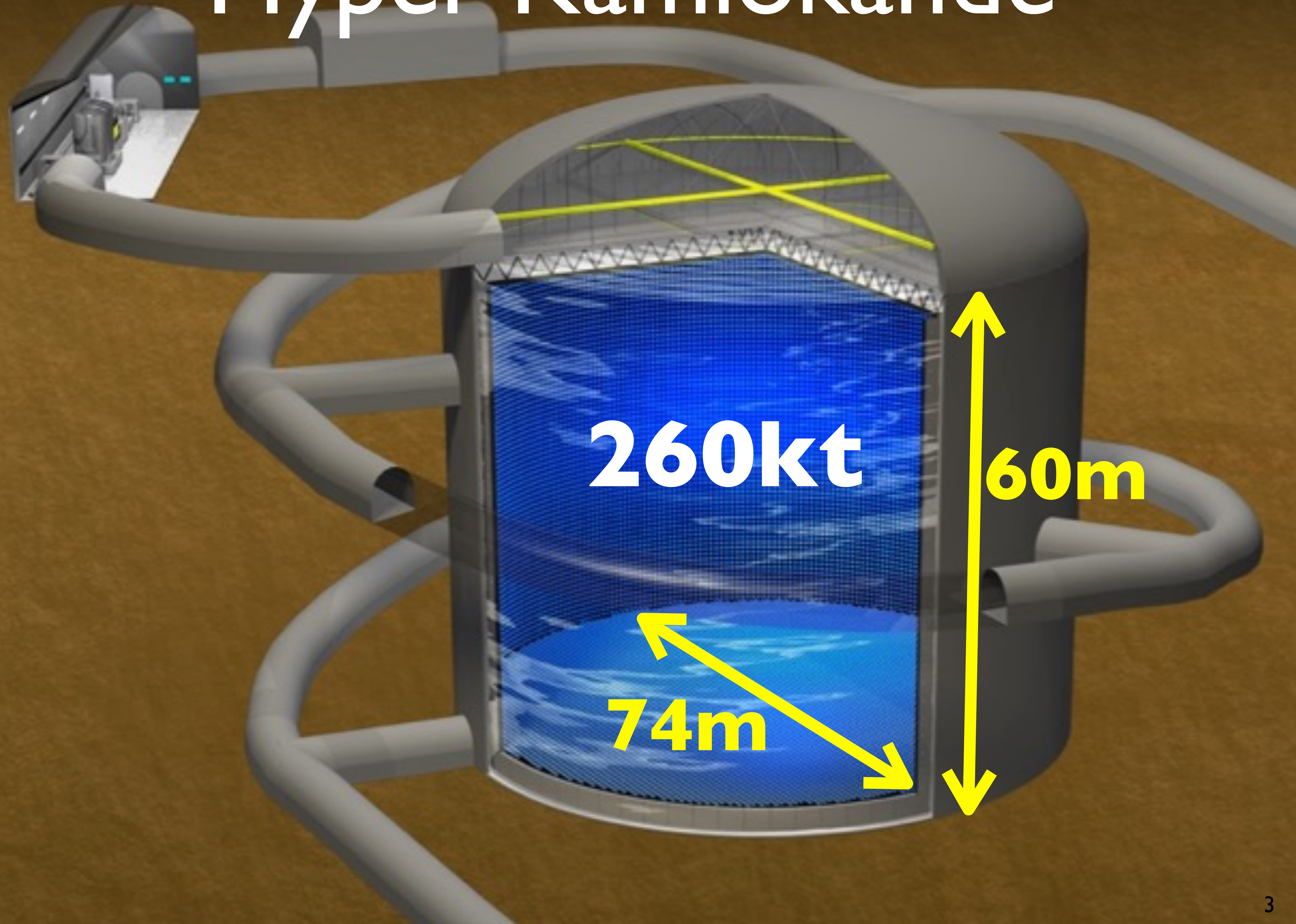
for Hyper-Kamiokande proto-collaboration

ニュートリノ研究会, 2018年2月24日

Hyper-K proto-collaboration

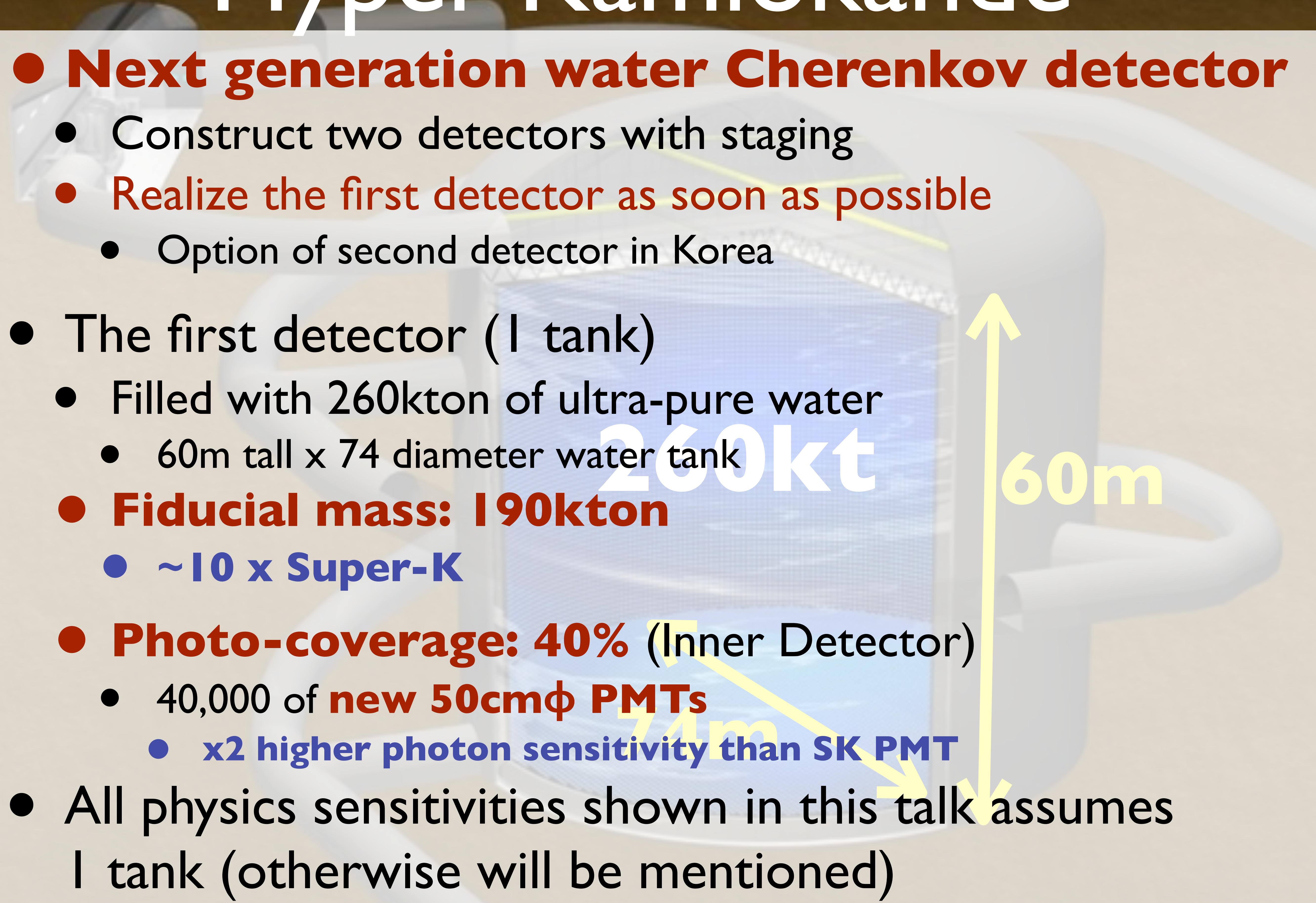
- ~300 collaborators
- 75 institutions from 15 countries
- ~70% of collaborators from oversea countries

Hyper-Kamiokande



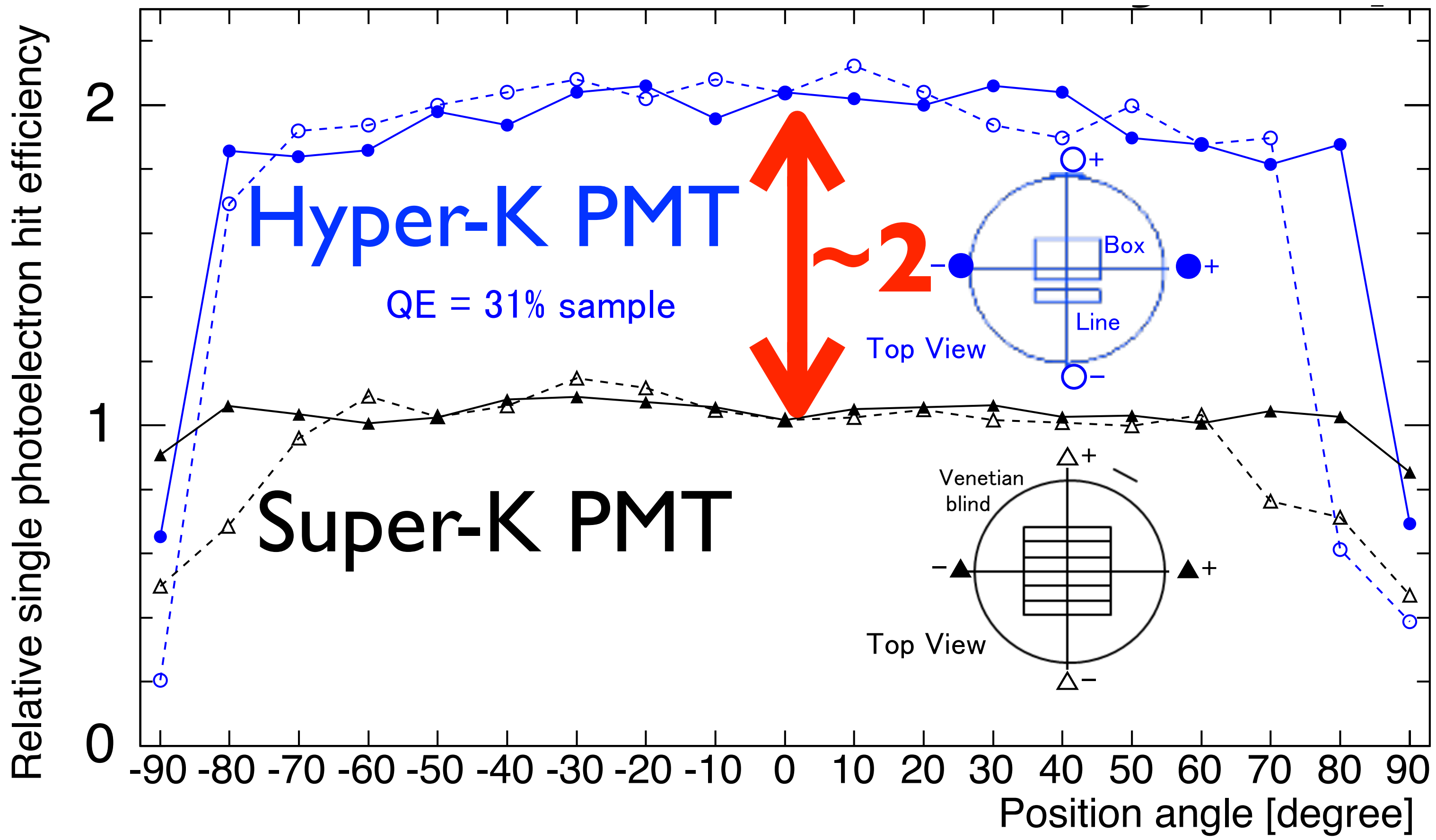
Hyper-Kamiokande

- **Next generation water Cherenkov detector**
  - Construct two detectors with staging
  - Realize the first detector as soon as possible
    - Option of second detector in Korea
- The first detector (1 tank)
  - Filled with 260kton of ultra-pure water
    - 60m tall x 74 diameter water tank
  - **Fiducial mass: 190kton**
    - **~10 x Super-K**
  - **Photo-coverage: 40%** (Inner Detector)
    - 40,000 of **new 50cmϕ PMTs**
      - **x2 higher photon sensitivity than SK PMT**
- All physics sensitivities shown in this talk assumes 1 tank (otherwise will be mentioned)

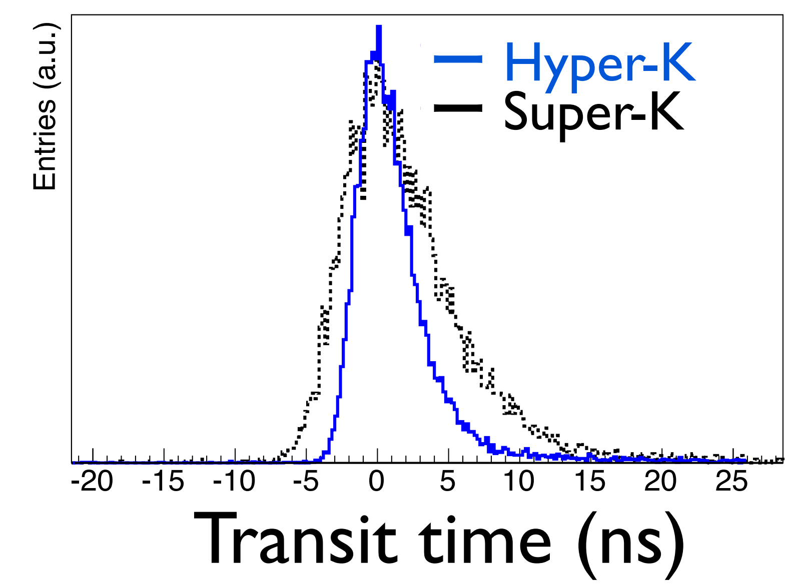


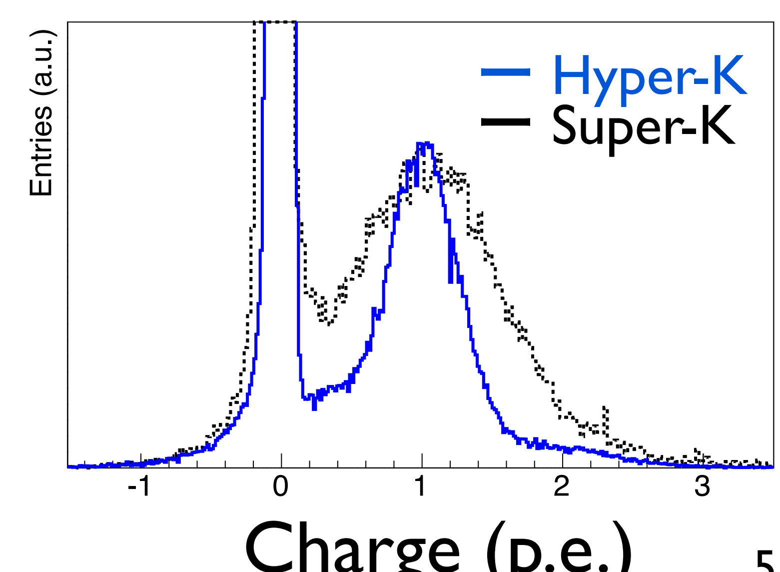
New 50cmΦ PMT for Hyper-K

Photo-detection efficiency (1p.e.)



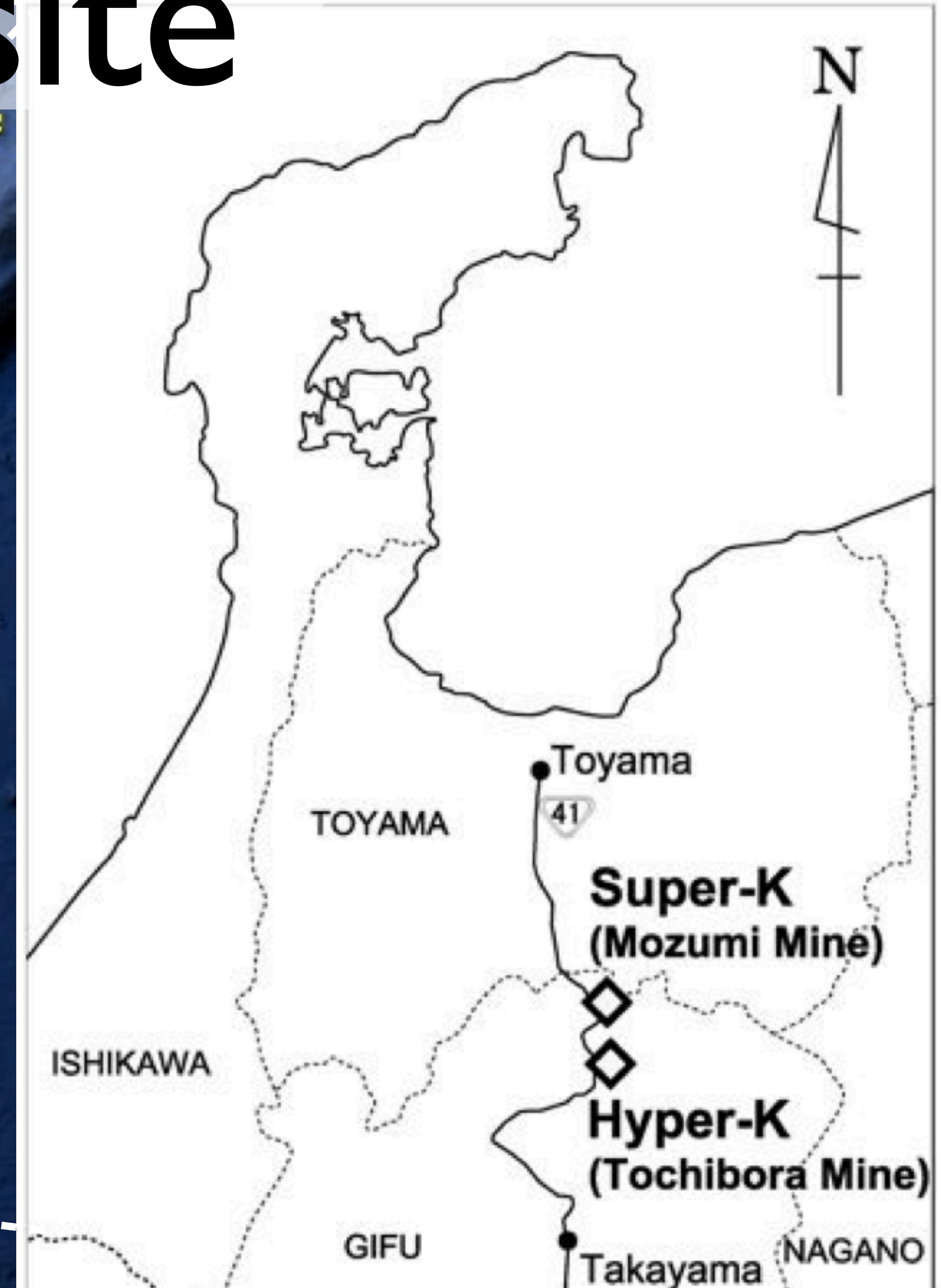
Box & line dynode PMT





- Twice better photo-detection efficiency than SK PMTs
- Timing resolution (TTS): 1.1ns
  - cf. SK PMT: 2.1ns
- Higher pressure tolerance: >80m

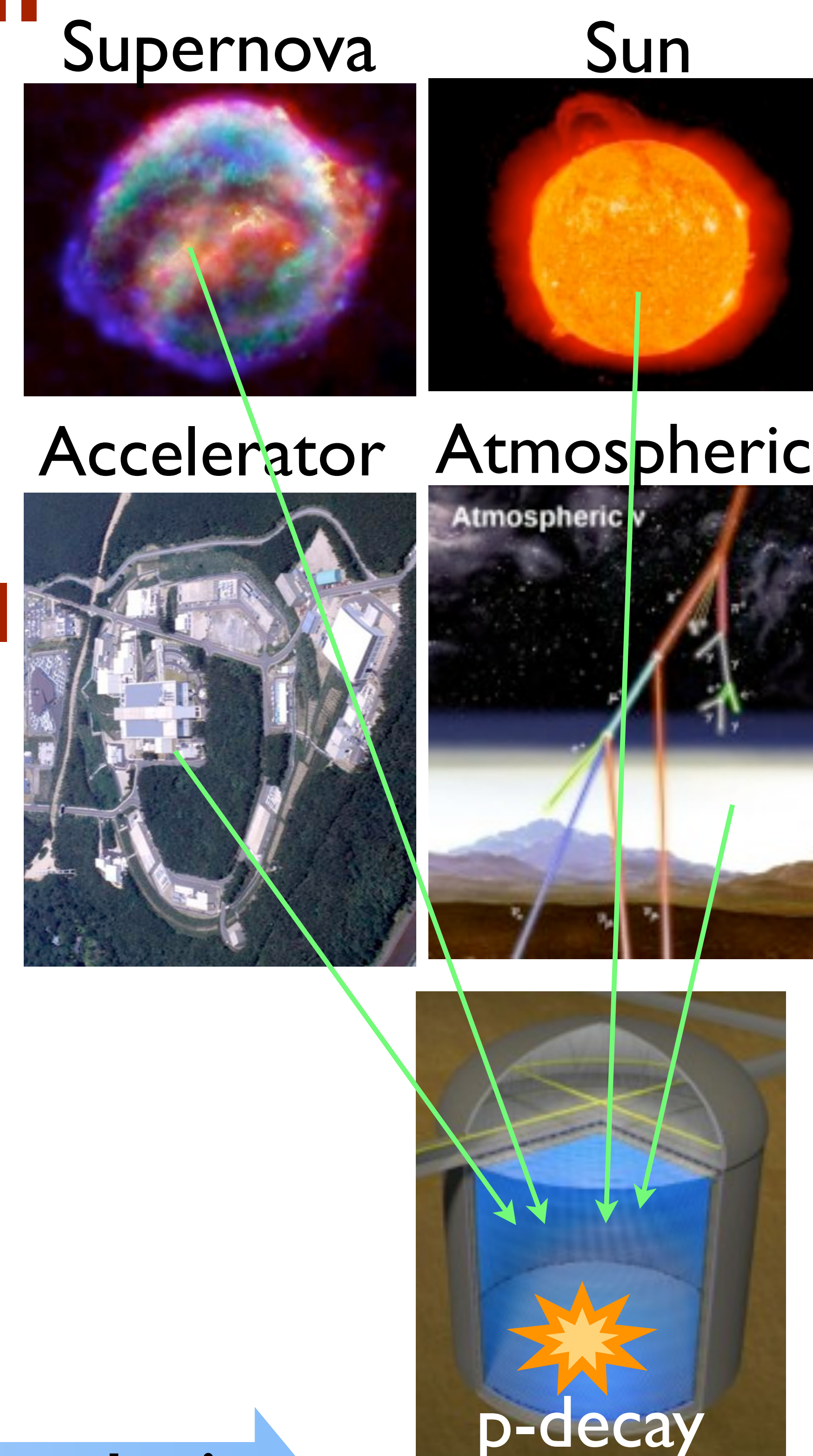
Detector site

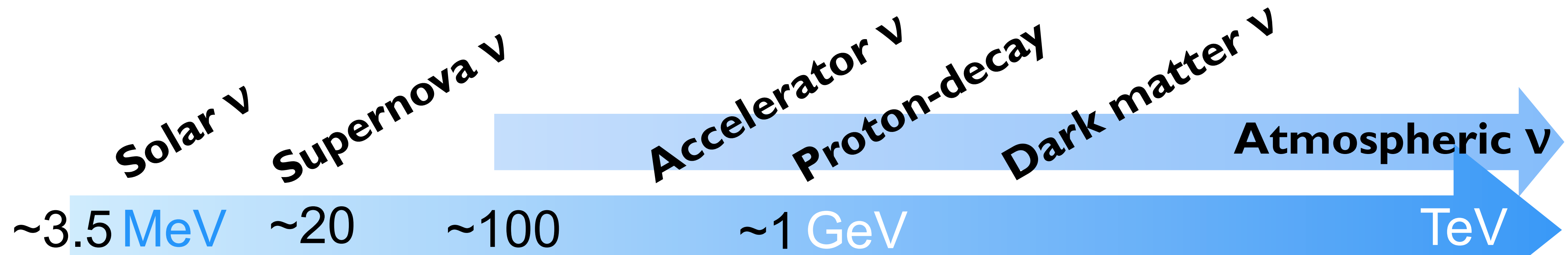


- The candidate site locates under Mt. Nijugo-yama
  - ~8km south from Super-K
  - Identical baseline (295km) and off-axis angle (2.5deg) to T2K
- Overburden ~650m (~1755 m.w.e.)

Hyper-K: multi-purpose detector

- **Comprehensive study of ν oscillation**
  - CPV: 76% of δ space w/ 3σ, <22° precision
  - MH determination for all δ with J-PARC/Atm ν
  - θ_{23} octant determination at $|\theta_{23}$-45°|>2°
  - <1% precision of Δm^2_{32}
  - Test standard ν oscillation scenario w/ acc/atm ν
- **Proton decay 3σ discovery potential**
  - 1×10^{35} years for $p\rightarrow e^+\pi^0$
  - 3×10^{34} years for $p\rightarrow \nu K^+$
- **Astrophysical neutrino**
  - Solar ν: test standard matter effect (MSW) model
  - Supernova ν, supernova relic-ν
  - Dark matter neutrinos from Sun, Galaxy, Earth

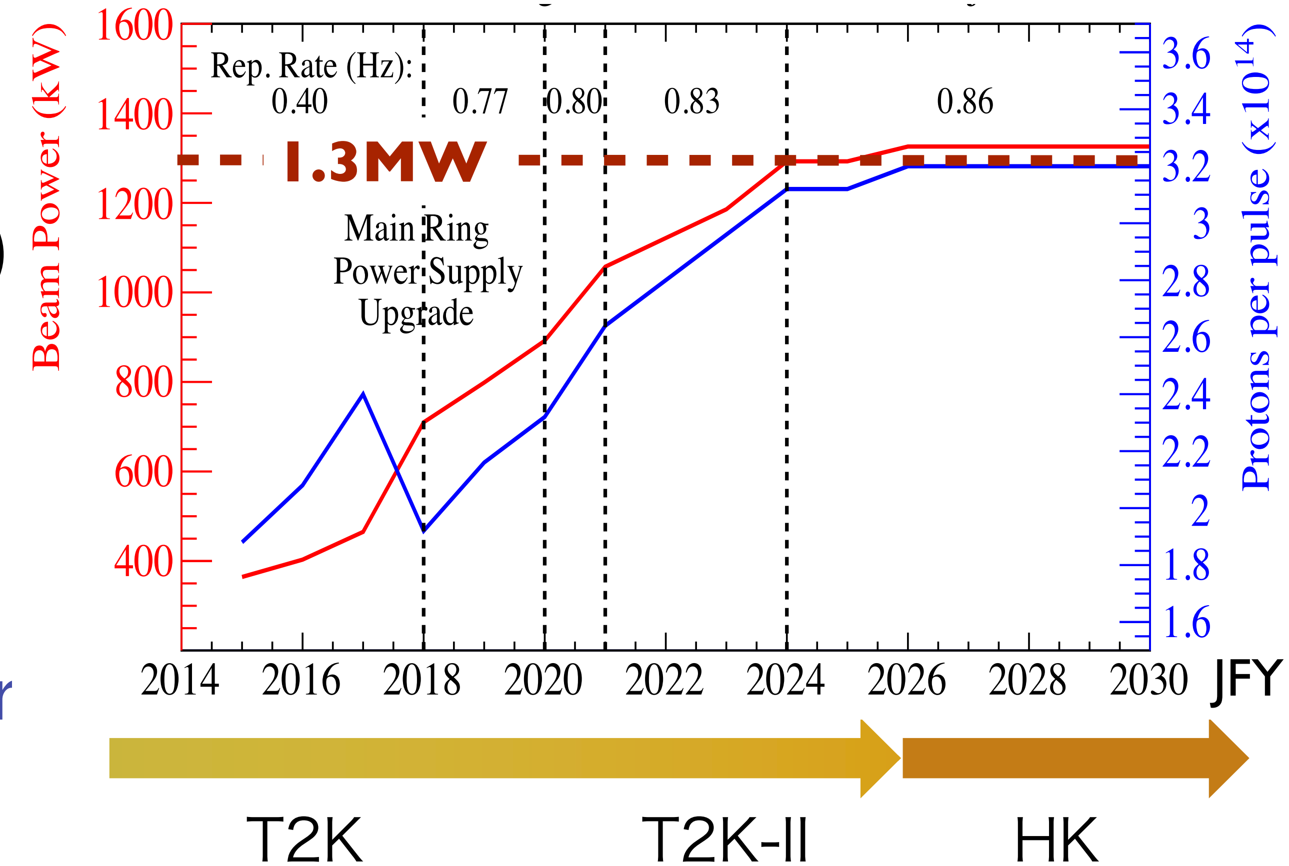


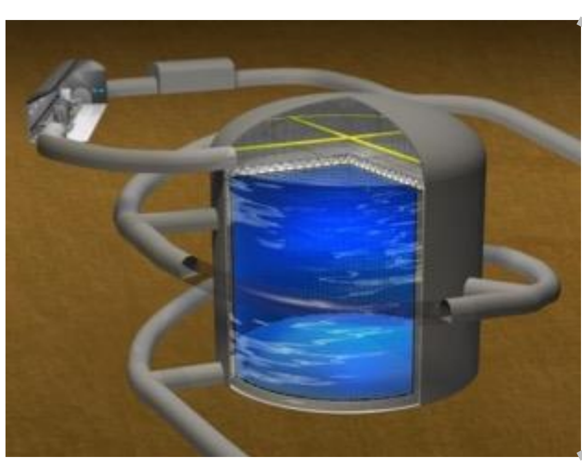


Accelerator based neutrinos

- High quality & high intensity neutrino beam
- 2.5 deg. off-axis narrow band neutrino beam (identical to T2K)
- Beam power: 1.3MW (before Hyper-K starts)
    - KEK Project Implementation Plan: top priority on 'J-PARC upgrade for Hyper-K'

J-PARC MR Fast Extraction Power Projection



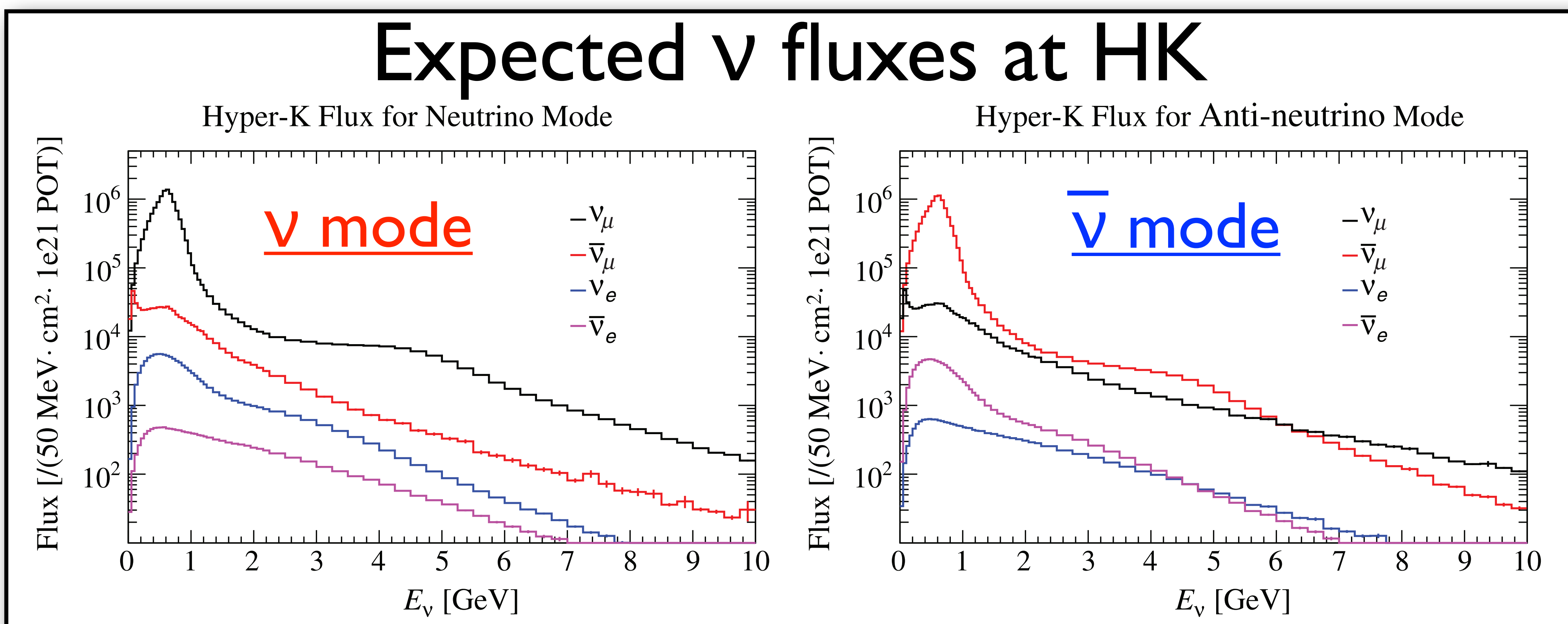


Hyper-K

J-PARC
Accelerator Complex

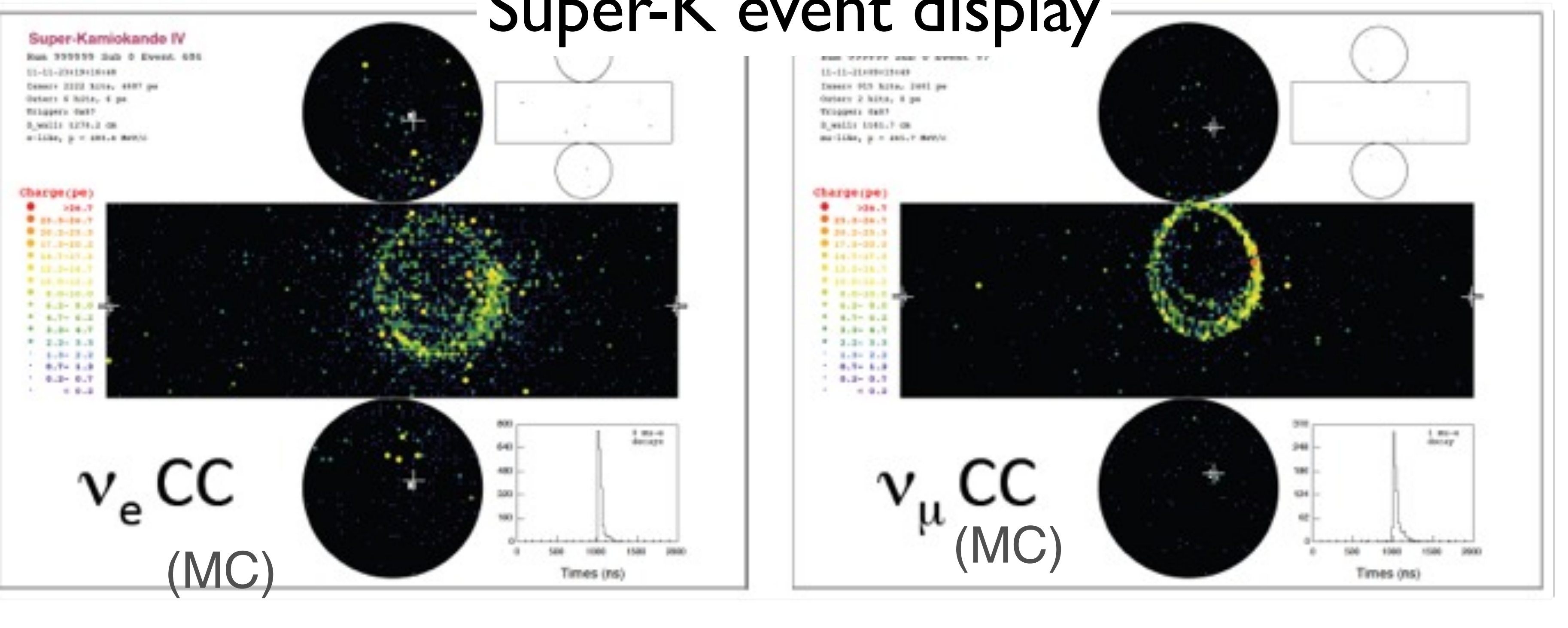
J-PARC to Hyper-K

- Relatively short baseline (295km, same as T2K)
  - Less matter effect: good for CP measurement
  - Complementary to other experiments with longer baseline (>1000km)
- 2.5 deg. Off-Axis beam (same as T2K)
- Low energy (~0.6GeV) and narrow band beam
  - Peak around oscillation maximum
  - Good match for Water Cherenkov detector

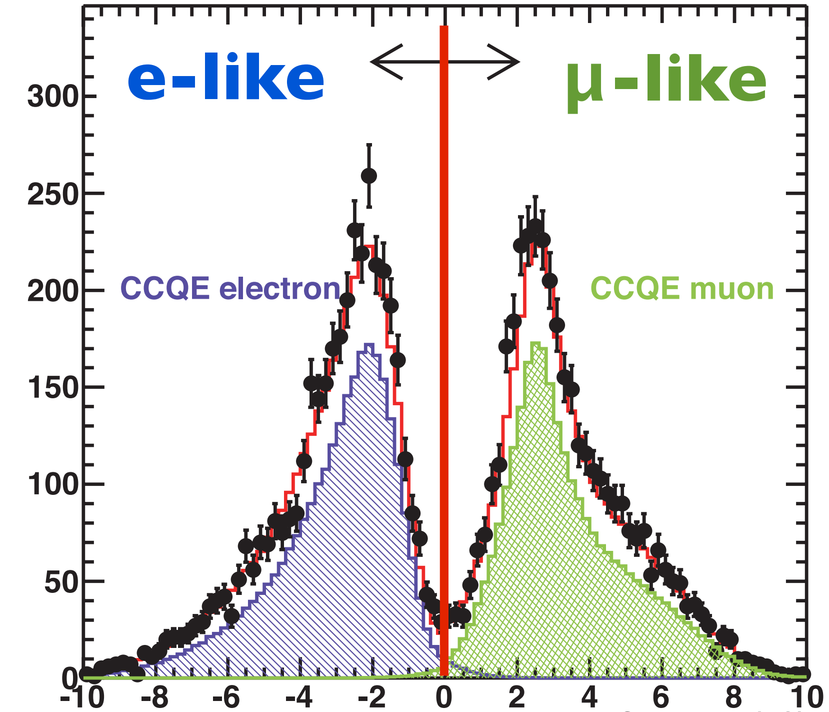


Detector performance

Super-K event display



SK atmospheric ν

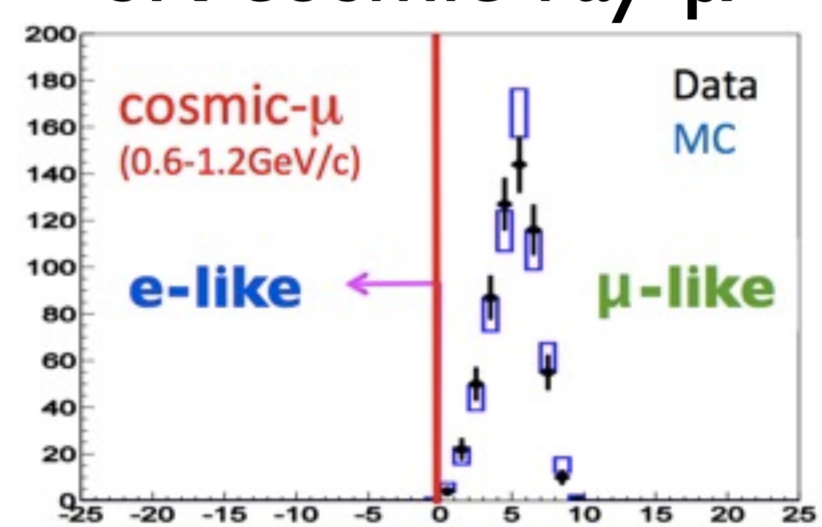


PID likelihood

- Large mass (~10 x Super-K FV)
  - Statistics is always critical
- Excellent particle ID (e/μ)
  - Mis-identification <1%
- Energy resolution e/μ ~3%
- Quasi-elastic is dominant (sub-GeV)

  → Clean one-ring event

SK cosmic-ray μ



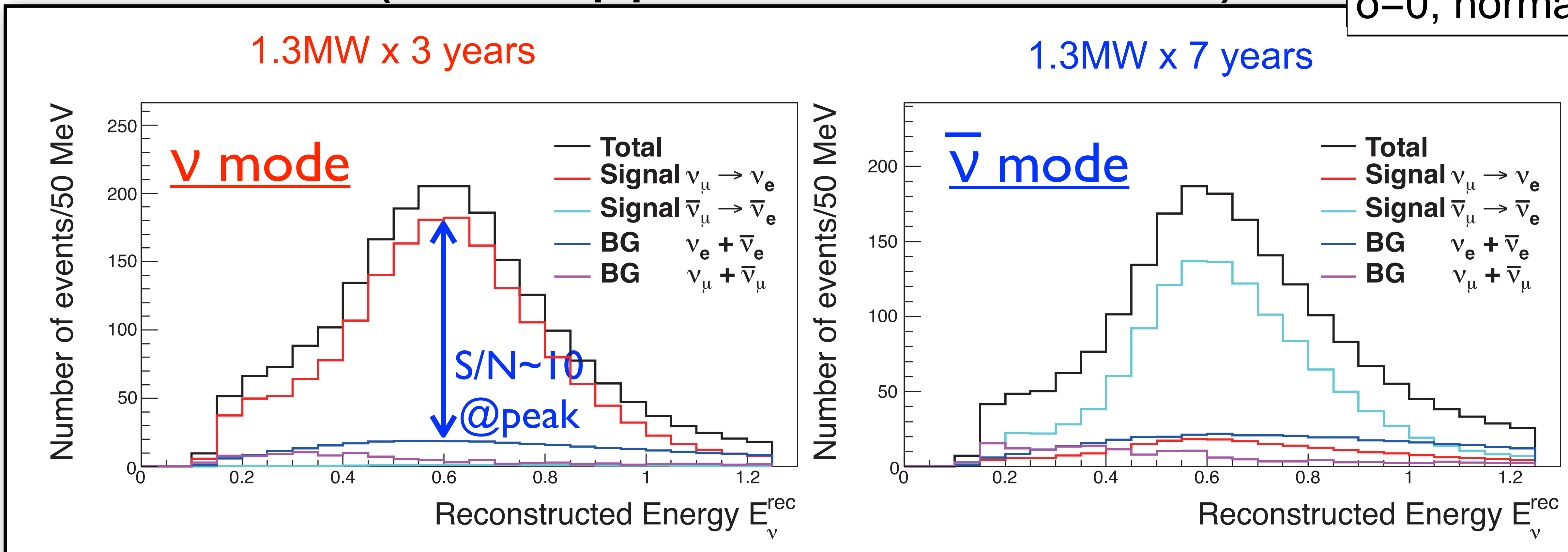
PID likelihood

mis-PID:
Data: 0.00±0.16(stat.)%
MC : 0.10±0.10(stat.)%

ν_e CC candidates

Reconstructed ν energy distributions (after applied selection cuts)

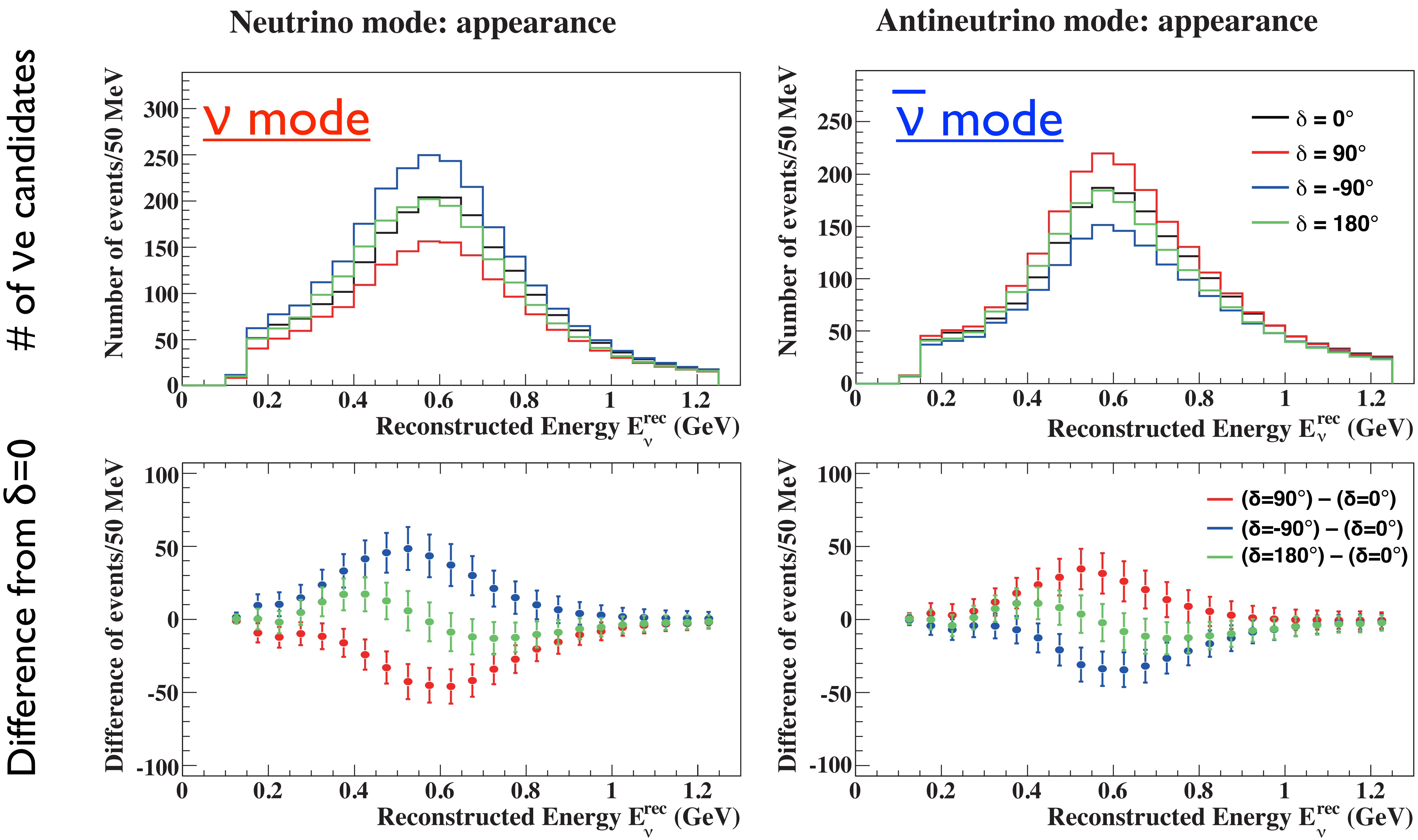
$\sin^2(2\theta_{13})=0.1$, $\delta=0$, normal MH



for $\delta_{CP}=0$	Signal $\nu_\mu \to \nu_e$ CC	Wrong sign appearance	$\nu_\mu / \bar{\nu}_\mu$ CC	Beam $\nu_e / \bar{\nu}_e$ contamination	NC
ν beam	1,643	15	7	259	134
$\bar{\nu}$ beam	1,183	206	4	317	196

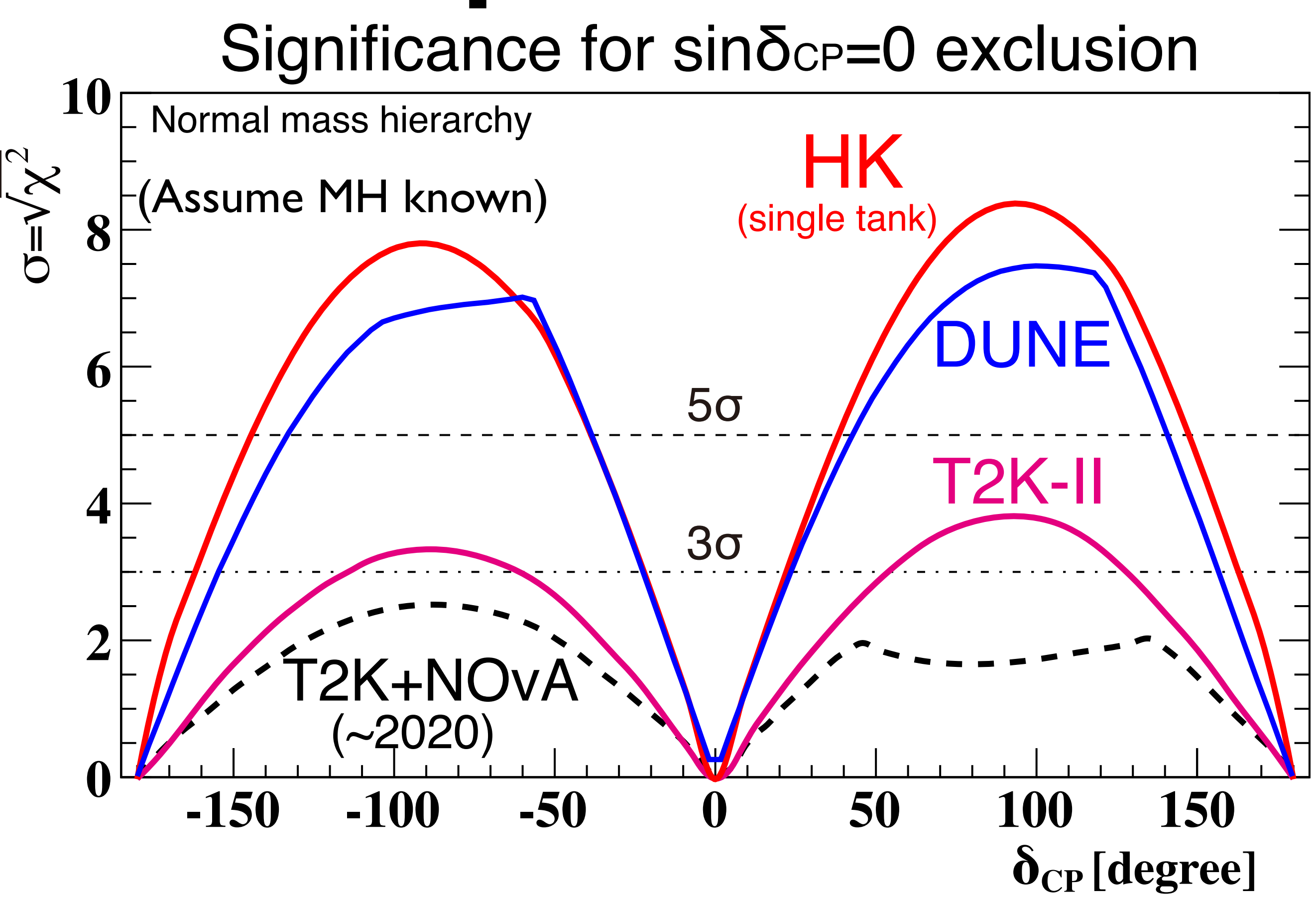
- S/N~10 at peak (>99% ν_μCC/NC bkg rejection)
  - ex. NC π0 bkg rejection efficiency: >99.5%

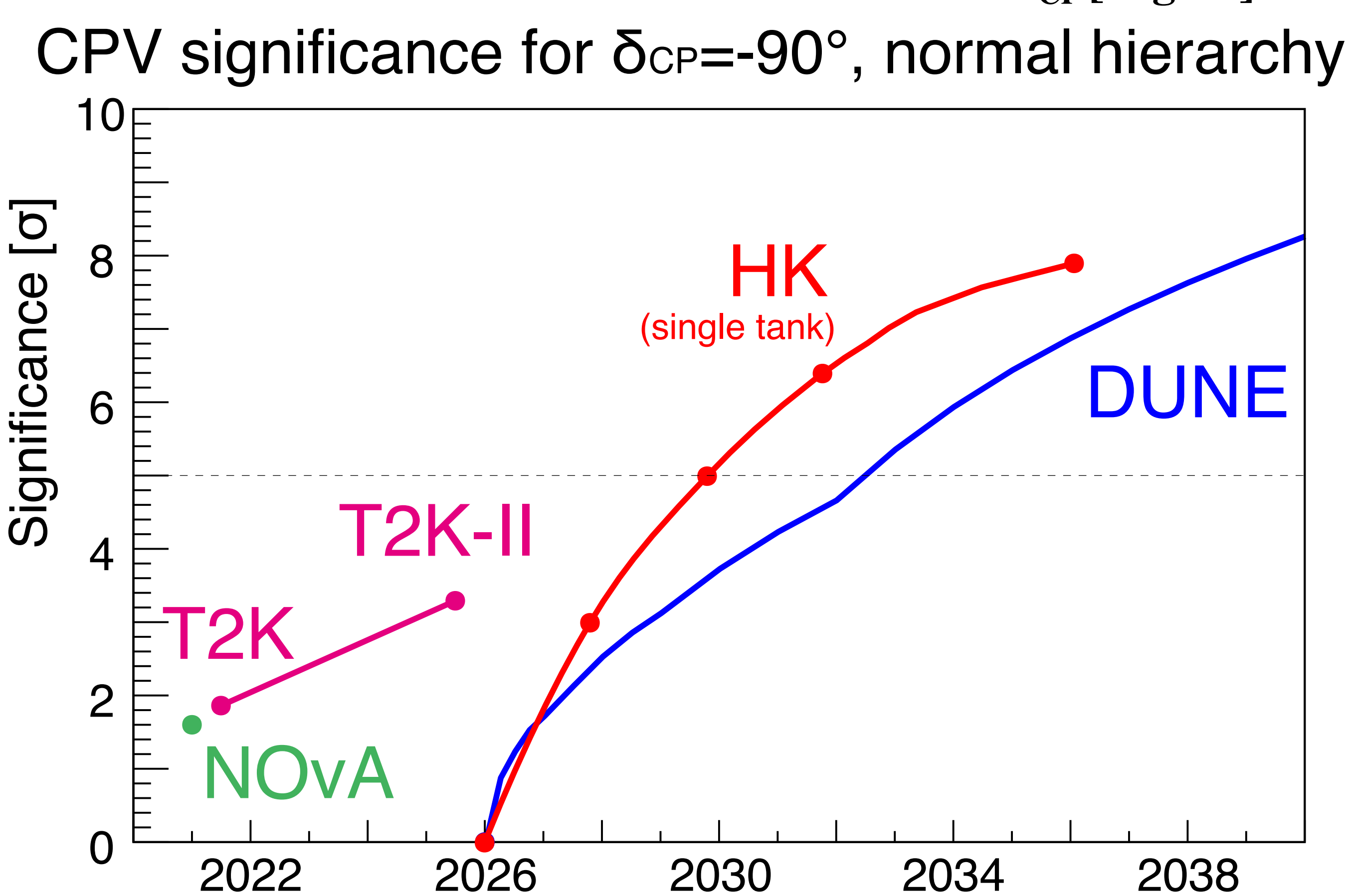
Effect of $\delta_{CP} \neq 0$



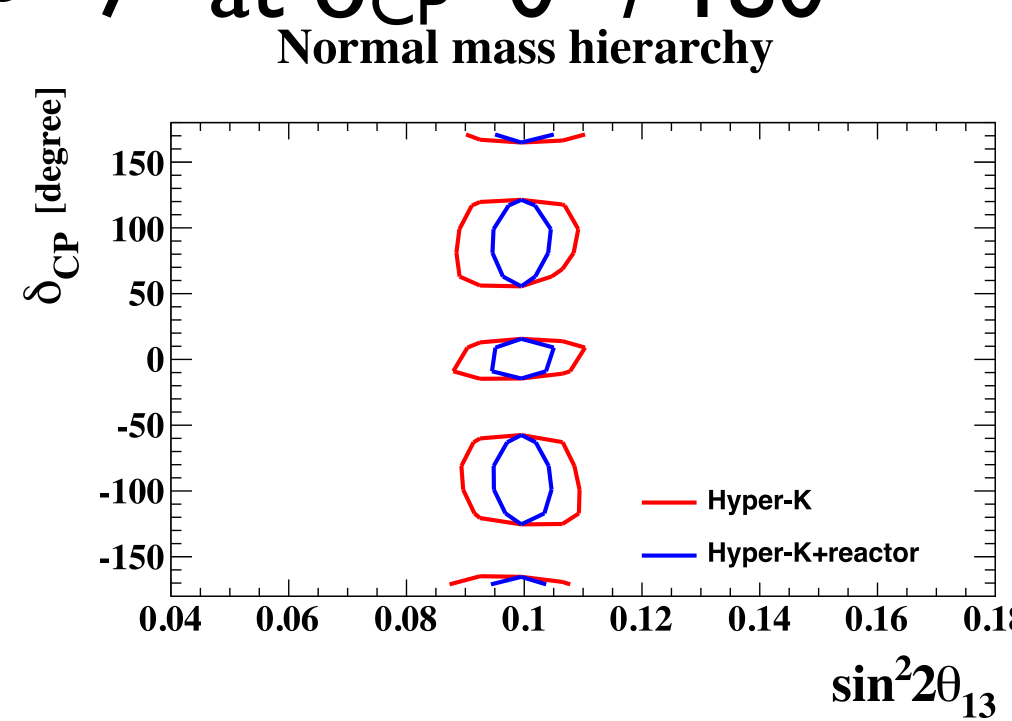
- Sensitive to all δ values
- also sensitive to any non-standard CPV, if any

Expected sensitivity for CPV



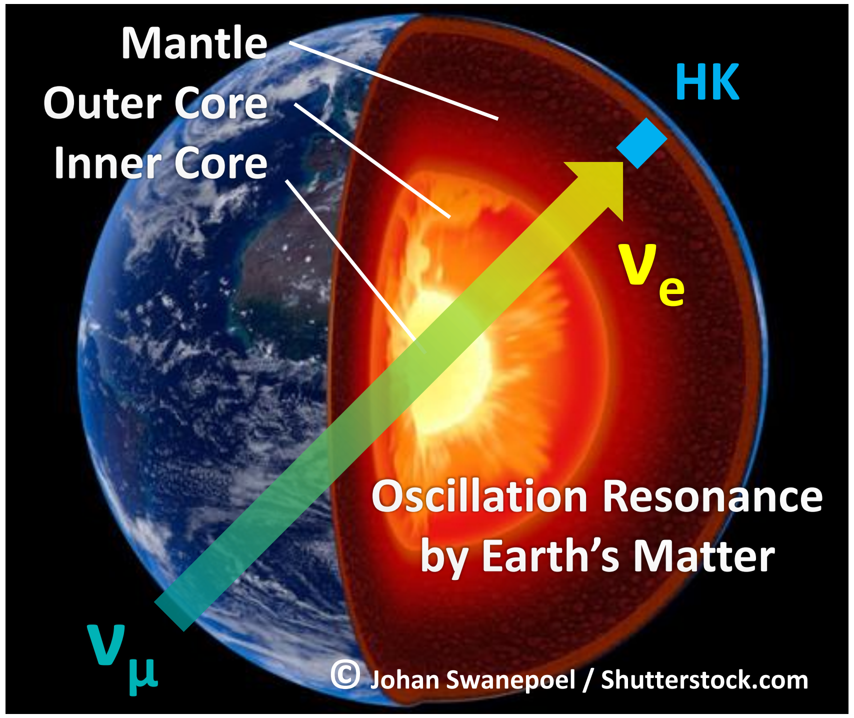


- $\sin\delta_{CP}=0$ exclusion:
  - ~8σ significance if $\delta_{CP}=\pm90°$
  - ~6σ significance if $\delta_{CP}=\pm45°$
- Observe CPV for 76% (58%) of δ_{CP} space w/ 3σ (5σ) significance
- δ_{CP} resolution:
  - 22° at $\delta_{CP}=\pm90°$
  - 7° at $\delta_{CP}=0°$ / 180°

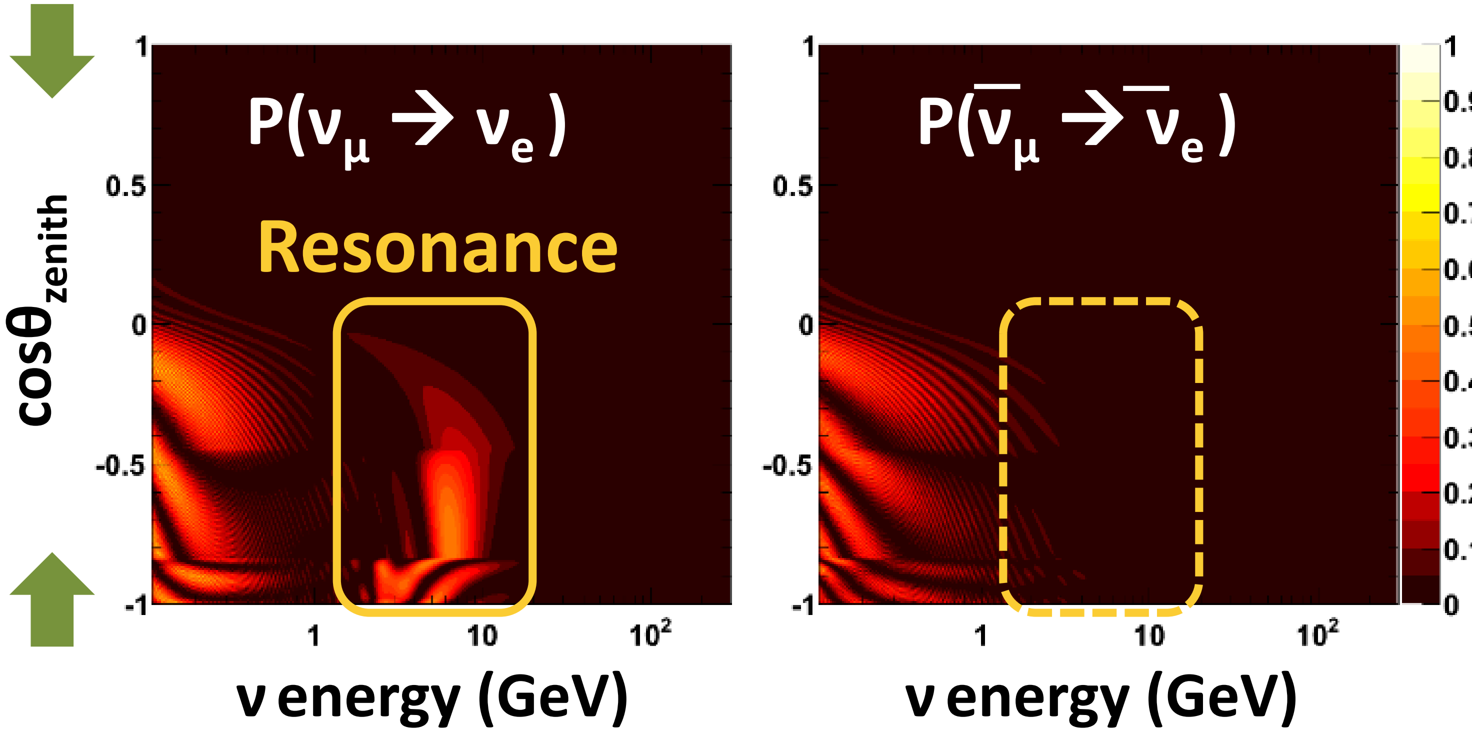


Mass Hierarchy determination in Hyper-K

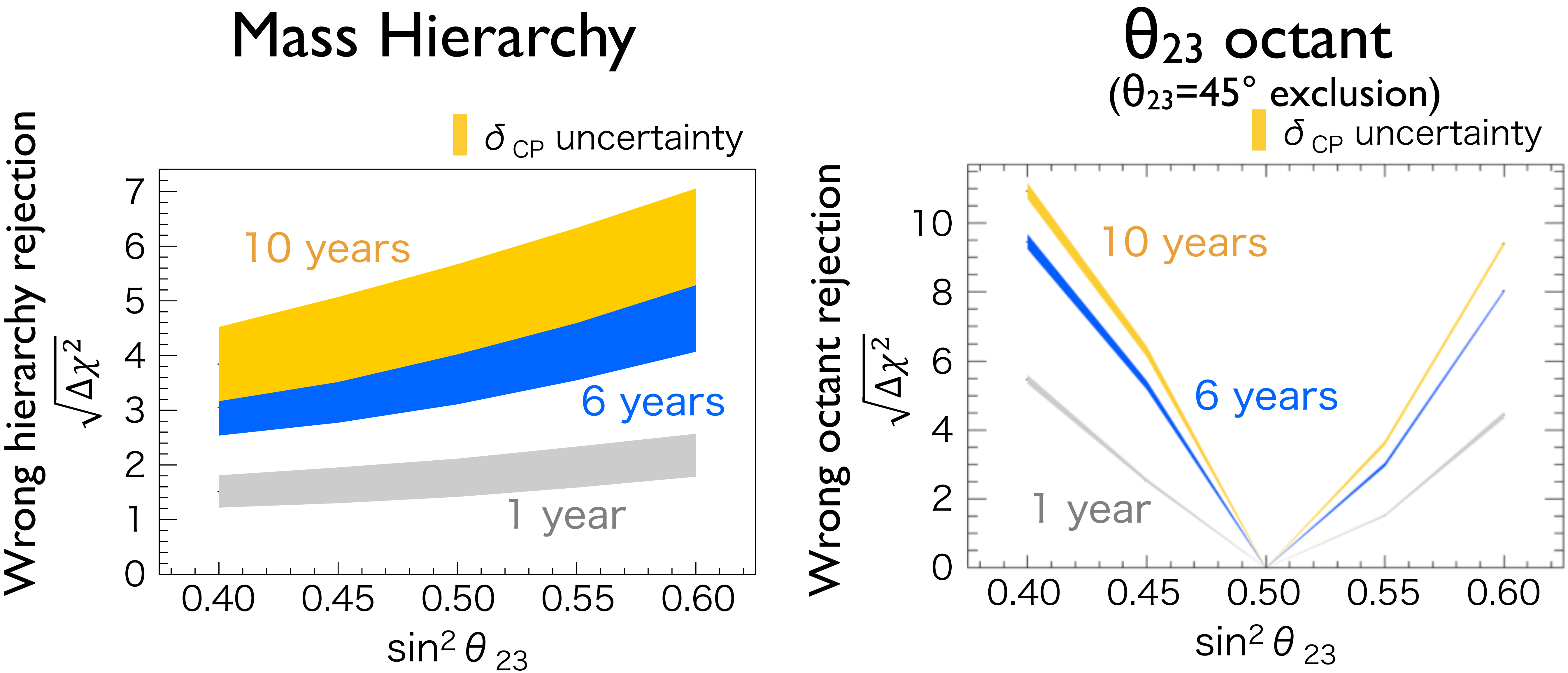
- Earth matter effect in upward-going multi-GeV ν_e sensitive to mass hierarchy
  - Earth matter effect 'resonance' appears in ν_e app. for NH, in $\bar{\nu}_e$ app. in IH
- Combination of atmospheric ν and beam ν to determine mass hierarchy



Normal hierarchy case (opposite in inverted case)



Mass Hierarchy sensitivity in Hyper-K



- Mass hierarchy and θ_{23} octant can be determined ($\geq 3\sigma$) within several years for the nearly entire parameter space

Systematic uncertainties

- Syst. errors based on SK/T2K experience and prospect
  - Error matrices of T2K adopted in HK sensitivity
  - Near detector: constrain cross section error w/ water target
  - Far detector: systematic error reduced by large stat. atm-ν

Assumed syst. uncertainties for sensitivity studies

		Flux & ND-constrained cross section	ND-independent cross section	Far detector	Total	T2K (2017)
ν mode	Appearance	3.0%	0.5%	0.7%	3.2%	6.1%
	Disappearance	3.3%	0.9%	1.0%	3.6%	4.4%
$\bar{\nu}$ mode	Appearance	3.2%	1.5%	1.5%	3.9%	6.5%
	Disappearance	3.3%	0.9%	1.1%	3.6%	3.8%

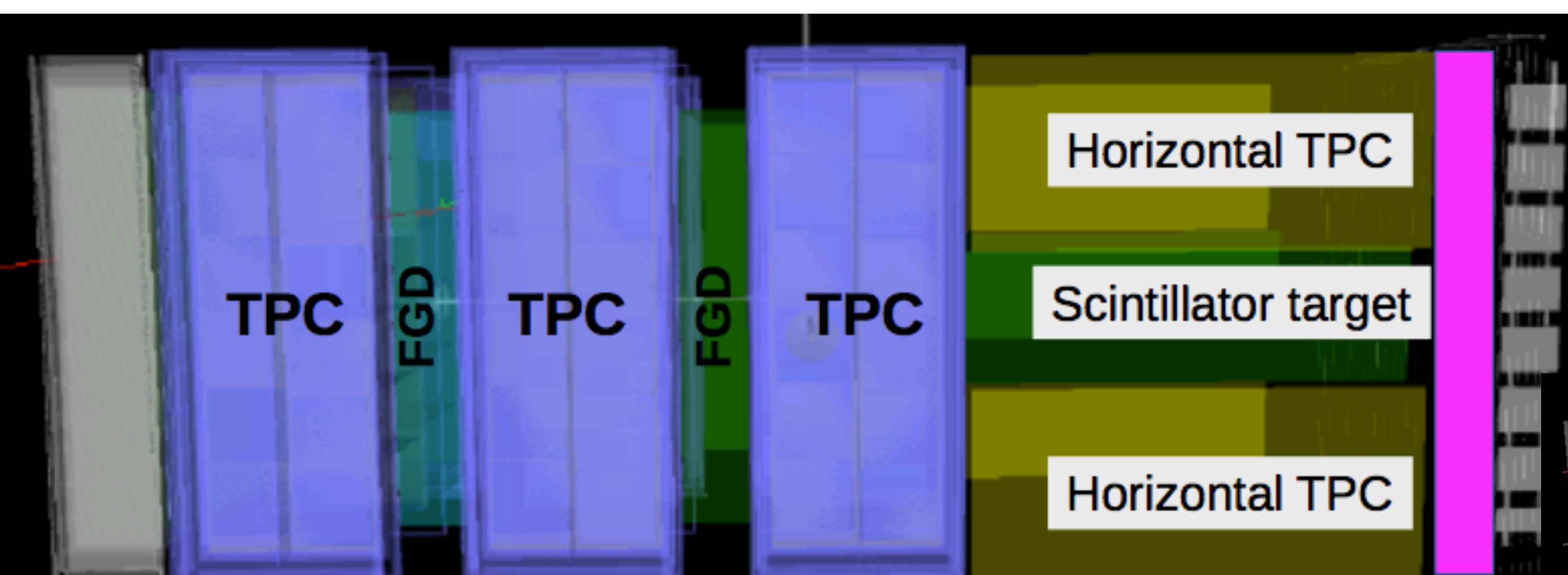
HK sensitivity studies assume uncertainties at 3~4% level

(cf. Uncertainty at the 6~7% level in T2K)

Dominant errors: electron (anti)neutrino cross section, near-to-far extrapolation of event rates, far detector modeling

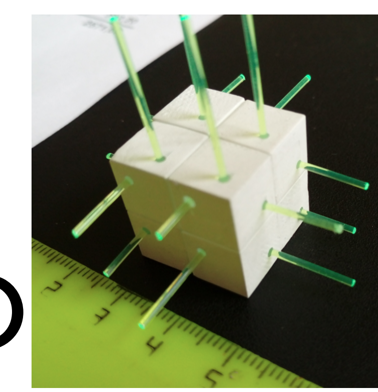
Near Detector Upgrade

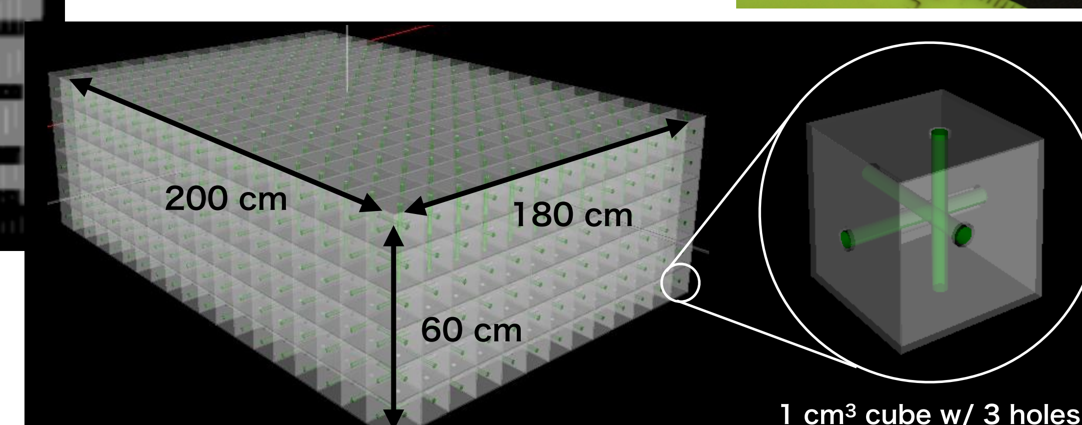
- Near and intermediate detectors for HK are being developed to control flux and cross-section systematic errors
- Will continue using the INGRID on-axis and magnetized ND280 off-axis detectors
- Work within T2K to upgrade ND280 detector
  - See Satashita-san's talk for details



→High-granularity scintillator detector (SuperFGD) and 'high-angle' TPC

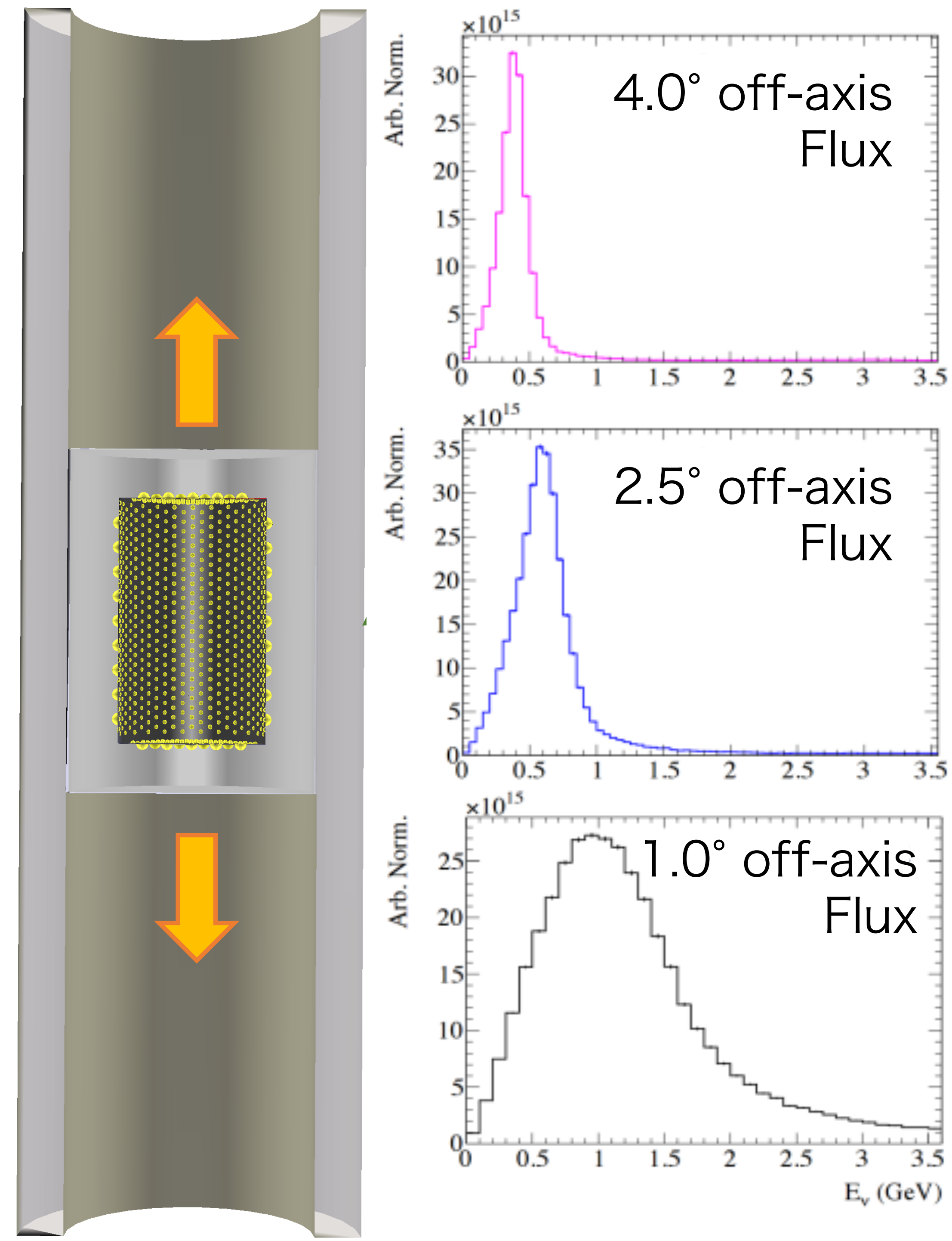
SuperFGD



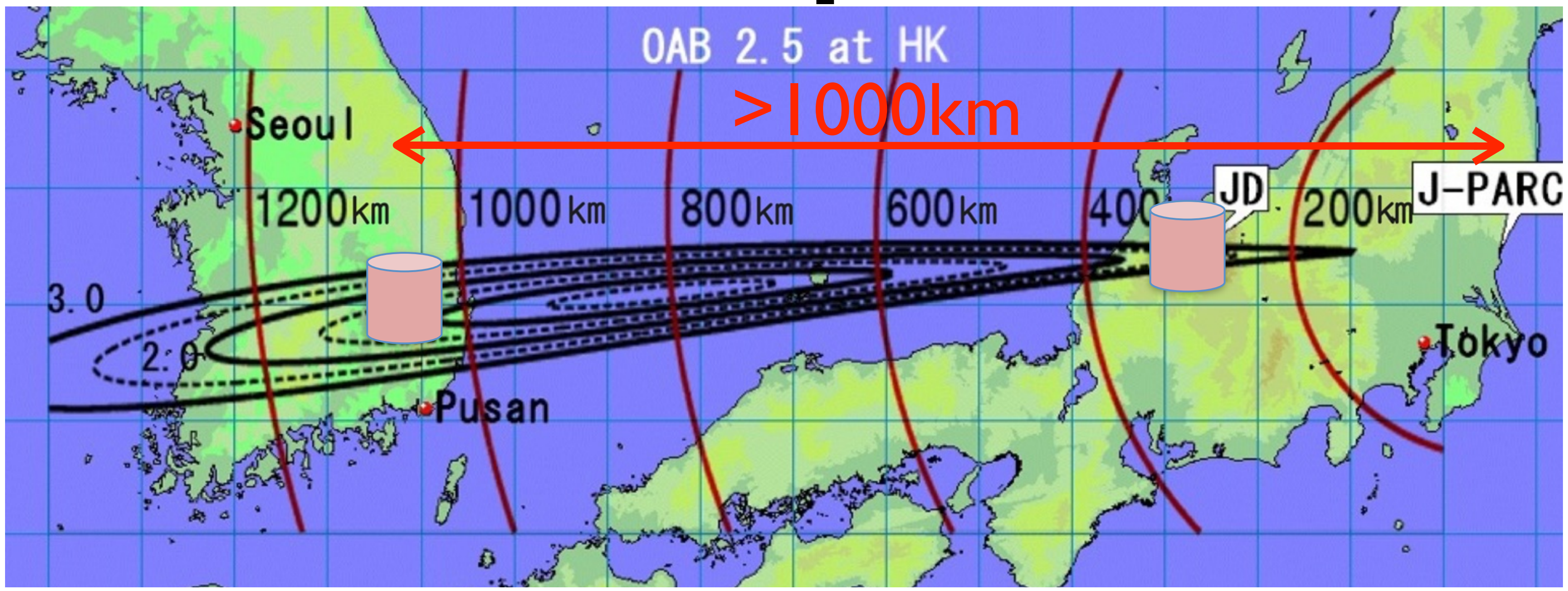


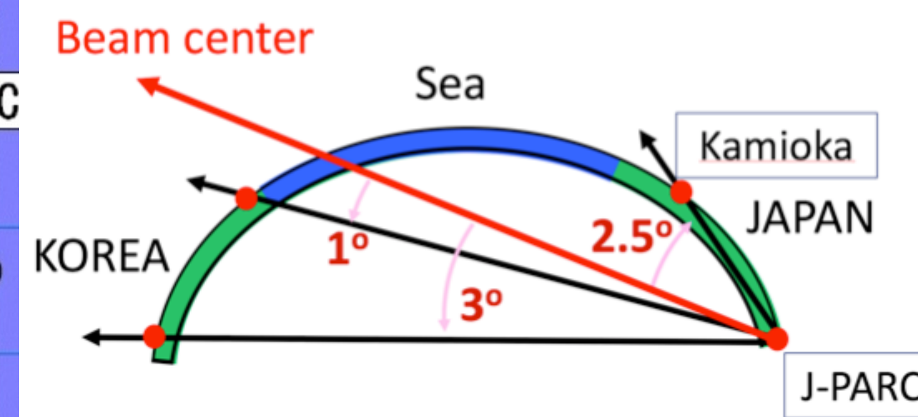
Intermediate Water Č detector

- Intermediate water Č detector proposed
  - Locate 1~2km downstream of J-PARC neutrino beam
  - J-PARC E61 (NuPRISM)
- Off-axis spanning (1°~4°) to probe neutrino energy vs. final state kinematics relationship
- Increase ν_e purity at higher angles: larger contribution from Kaon
  →Electron neutrino cross-section
  - Aim to $\sigma(\nu_e)/\sigma(\nu_\mu)$ cross-section ratio error down to 2~3%

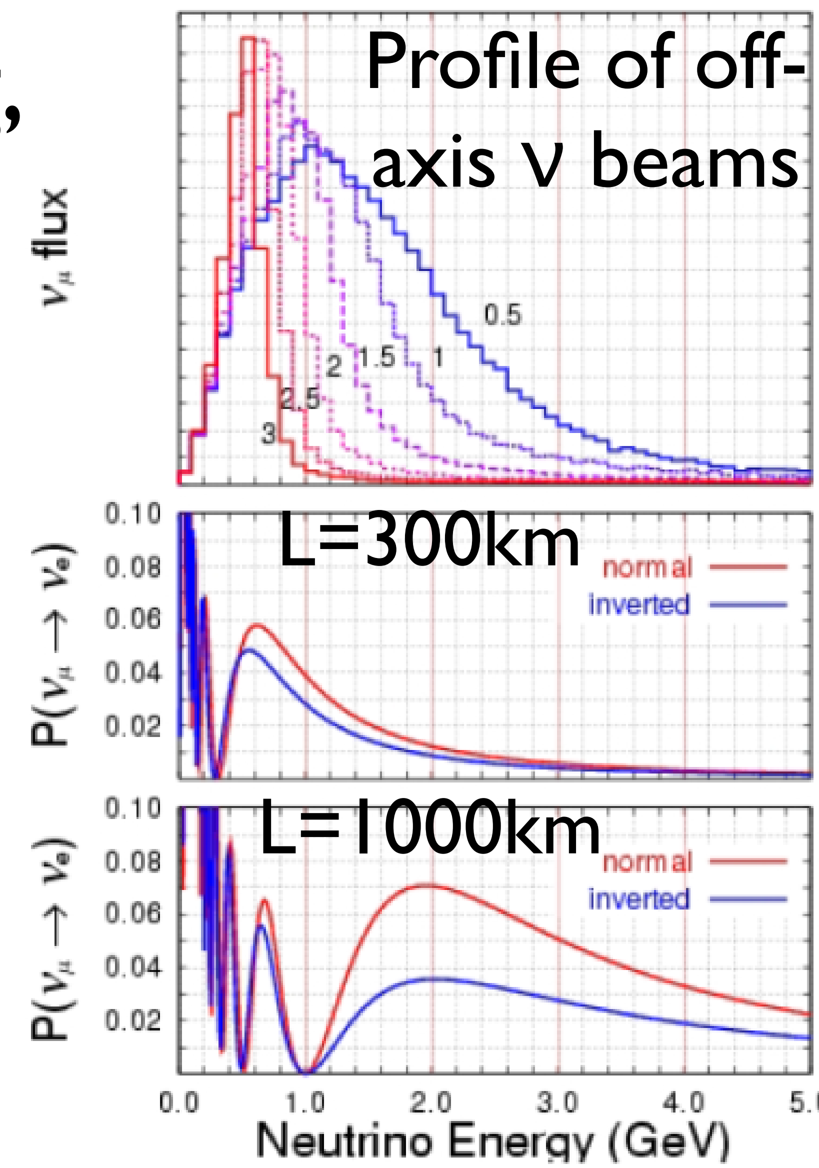


Korean option for 2nd tank





- Given the two tank design with staging, may benefit from building the second tank at a different baseline
- Option for second tank in Korea is being considered
- Advantage of 2nd detector in Korea:
  - CP effect at second oscillation maximum
  - Mass-hierarchy sensitivity to complement the measurement with atmospheric ν



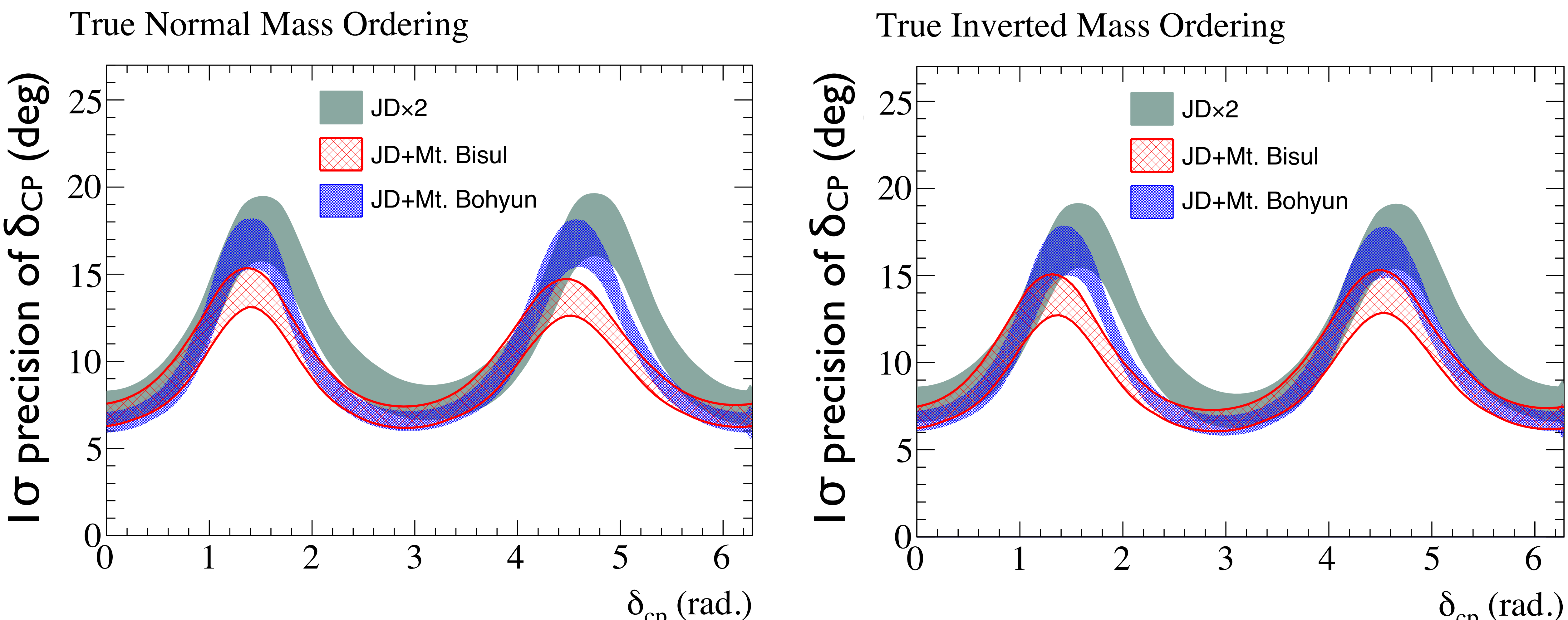
δ_{CP} resolution

arXiv:1611.06118

Two detectors in Japan

Second detector in Korea, two colours for two different candidate sites

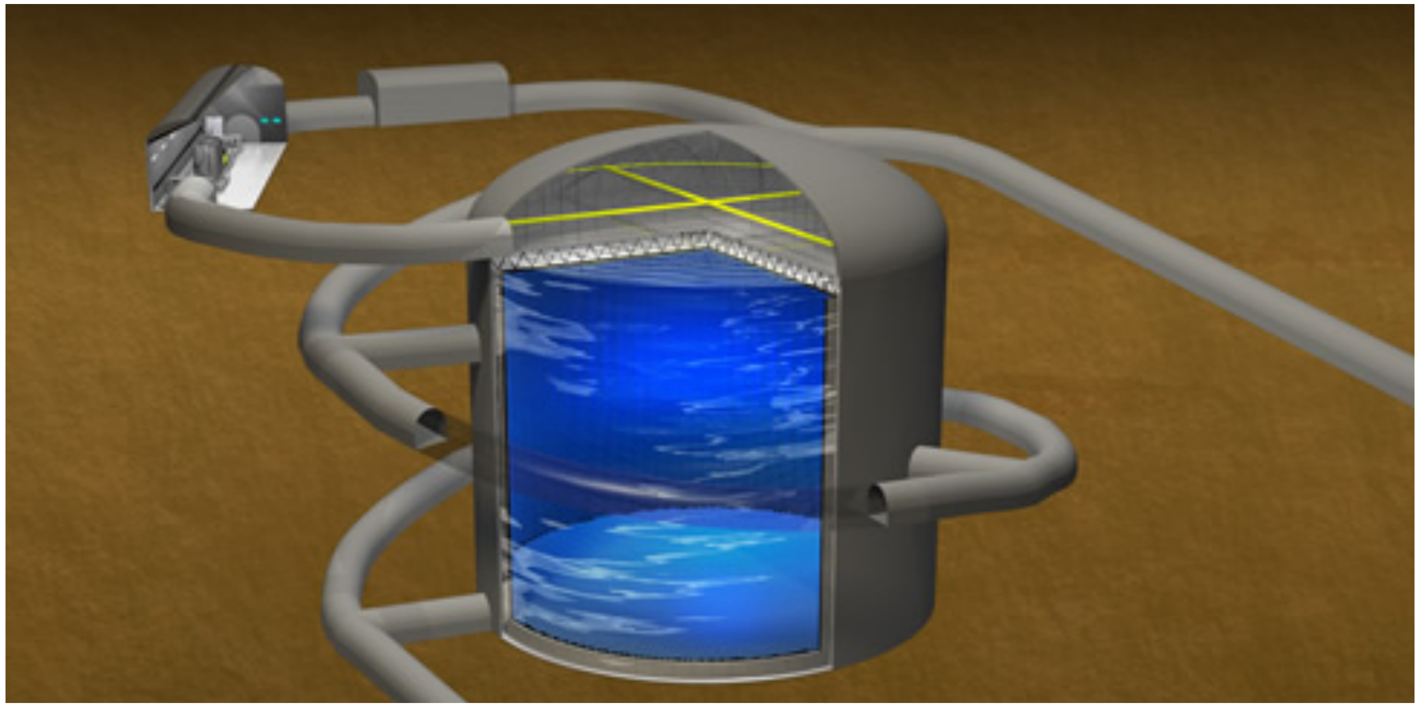
Band indicates range $0.4<\sin^2\theta_{23}<0.6$



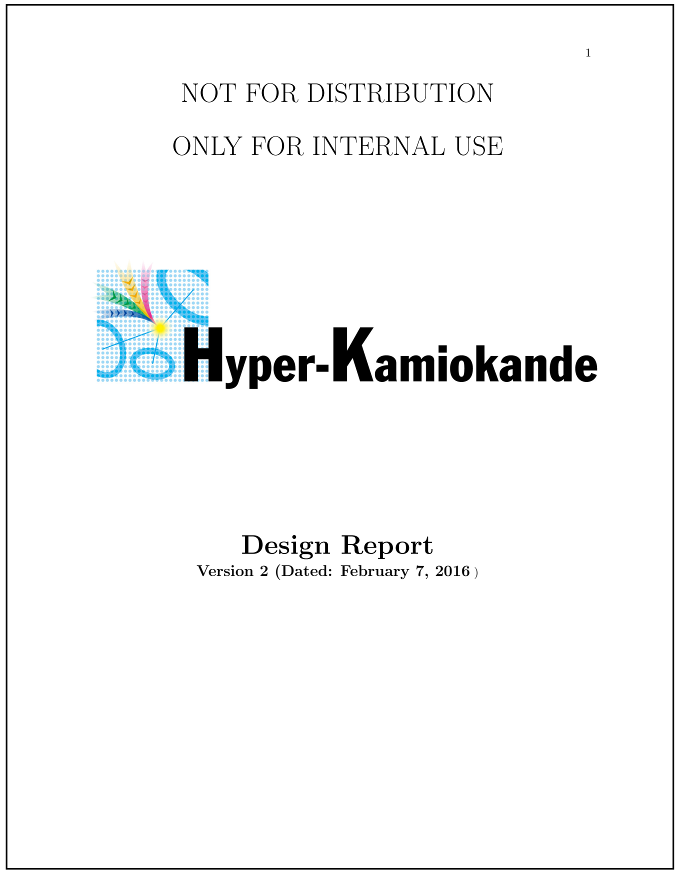
The second detector in Korea allows us to better measure the CP-phase, compared with both detectors in Japan

Project status in Japan

- 'Hyper-K Design Report' released
  - KEK preprint 2016-21, ICRR-Report-701-2016-1
- Strong commitment from host institutes: ICRR, U.Tokyo and KEK (MoU for Hyper-K)
- Strong support from Japanese communities
  - Cosmic-ray (CRC) and high-energy (JAHEP)
- Science Council of Japan selected Hyper-K as one of the top priority large-scale projects in 'Master Plan 2017'
- Hyper-K listed in 'Roadmap 2017' of MEXT (funding agency)
- Aim to begin operation in JFY 2026



Hyper-K Design Report


1

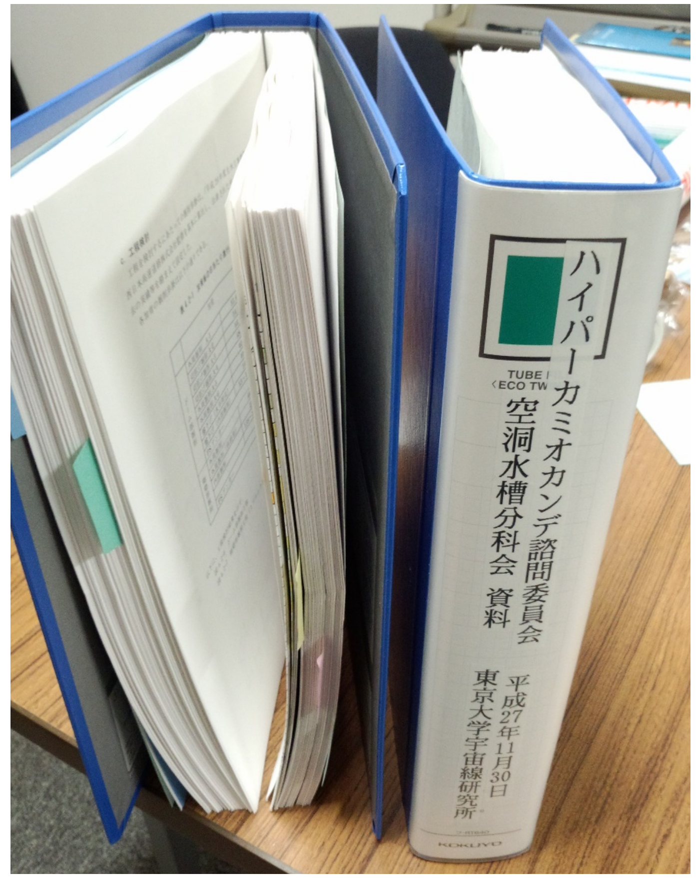
NOT FOR DISTRIBUTION

ONLY FOR INTERNAL USE

Hyper-Kamiokande

Design Report

Version 2 (Dated: February 7, 2016)



ICRR-Report-701-2016-1

KEK Preprint 2016-21

- Hyper-K baseline design and physics sensitivities in KEK preprint and ICRR report
- Being updated by adopting recent progress of detector design and physics sensitivity studies

Summary

- **Wide Physics topics, many discovery potentials**
  - ν CPV: 76% of δ space w/ 3σ, δ resolution <20°
  - Proton decay discovery sensitivity reaches 10^{35} years
  - SN burst, SN relic ν, indirect WIMP search, etc
  - Physics sensitivity enhanced with new photosensor
- **Project is boosted toward an early realization**
  - International proto-collaboration formed
  - Hyper-K Design Report released
  - Strong support from Japanese communities and host institutes
  - Selected in 'Master Plan' of Science Council of Japan
  - Listed in 'Roadmap 2017' of MEXT
  - Aim to begin the operation in JFY 2026
- **Open for new collaborators**