Status of the Hyper-Kamiokande Experiment

Carsten Rott

Sungkyunkwan University, Korea

rott@skku.edu

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Outline

- Introduction to Hyper-Kamiokande
- Overview of the detector
- Science goals and sensitvities
- Project status
- Summary & Conclusions

Hyper-Kamiokande Proto-Collaboration

- International proto-collaboration was formed in 2015
- ~300 members from 15+2 countries, ~80 institutes,
  - including 16 Korean members
- Two host institutes:
  - University of Tokyo / ICRR
  - KEK / IPNS

Documentation:

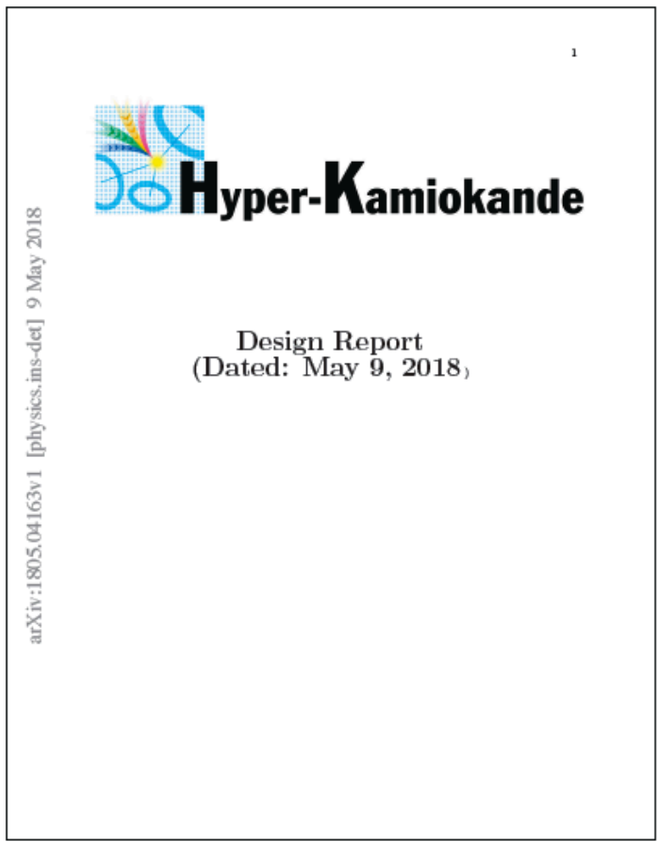
K. Abe et al. (Hyper-Kamiokande Collaboration),
Hyper-Kamiokande Design Report,
arXiV:1805.04163

K. Abe et al. (Hyper-Kamiokande Collaboration),
Physics potentials with the Second Hyper-Kamiokande detector in Korea,
PTEP 2018(2018) 6, 063C01

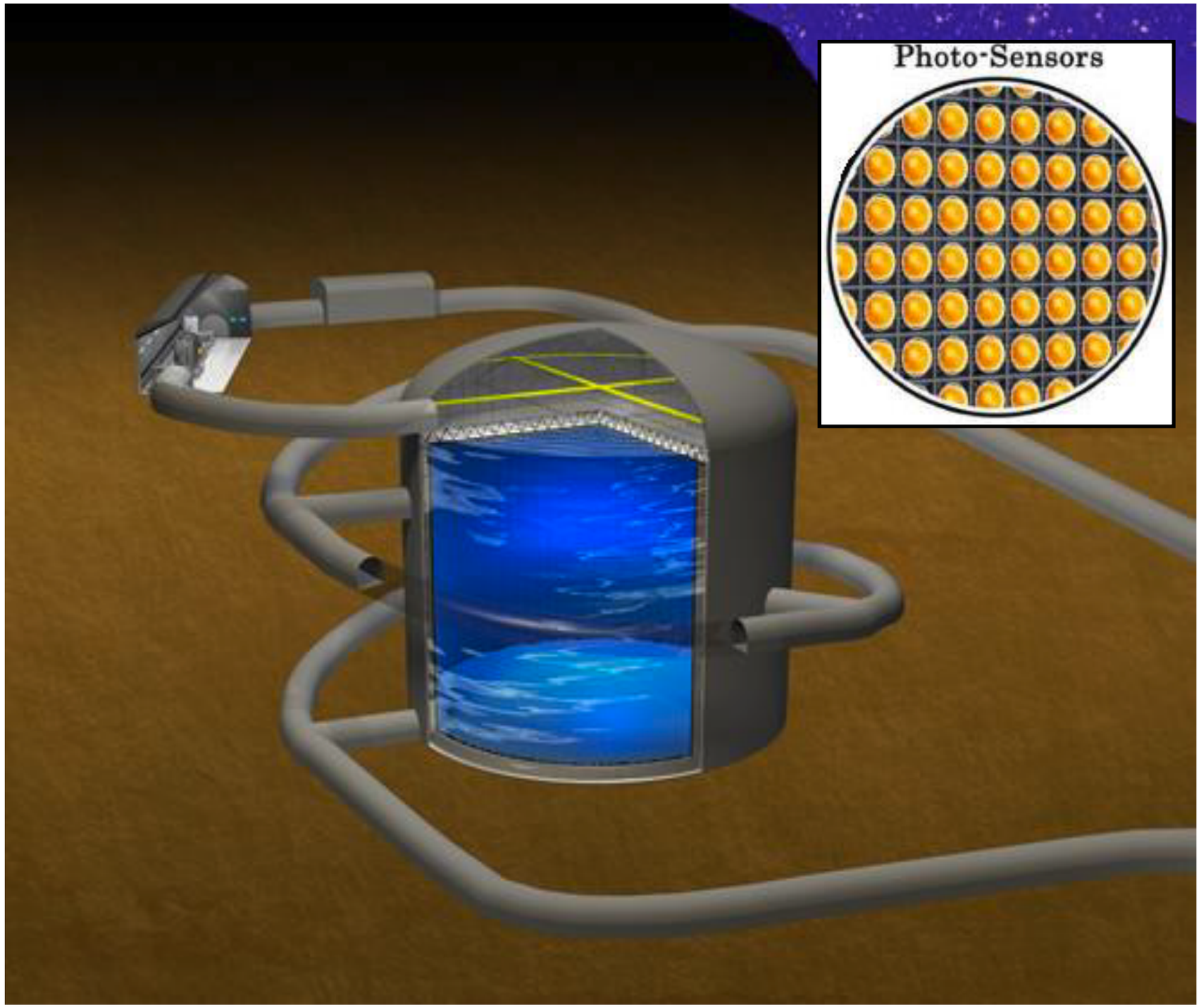
K. Abe et al. (Hyper-Kamiokande Working Group),
A Long Baseline Neutrino Oscillation Experiment Using J-PARC Neutrino Beam and Hyper-Kamiokande,
arXiv:1412.4673 [physics.ins-det]

K. Abe et al. **Letter of Intent: The Hyper-Kamiokande Experiment**,
arXiv:1109.3262 [hep-ex]

Based on Design Report



The Hyper-Kamiokande Project



Size: 60 m(H)x74m(D)
Total volume: 260 kt
Fiducial volume: 190 kt
(~10xSuper-K)

Inner detector (ID):
40,000 x 20” PMTs
40**% photocoverage**

Outer detector (OD):
6700 x 8” PMTs
1% photocoverage
OD water thickness: 1m barrel,
2 m top and bottom

2nd tank construction
Construction of 2nd tank in Korea
(1-3 deg off axis, 2nd oscill. maximum) is under study

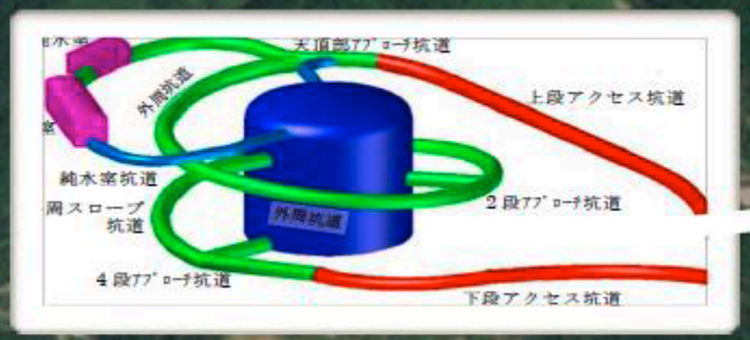
Detector location

Mt. Ikeno-yama
1000 m
SK

Maruyama

Excavated rock disposal site

Mt. Nijyugo-yama



650 m

HK

8 km south of Super-K
650 m rock overburden

Tunnel Entrance

Wasabo

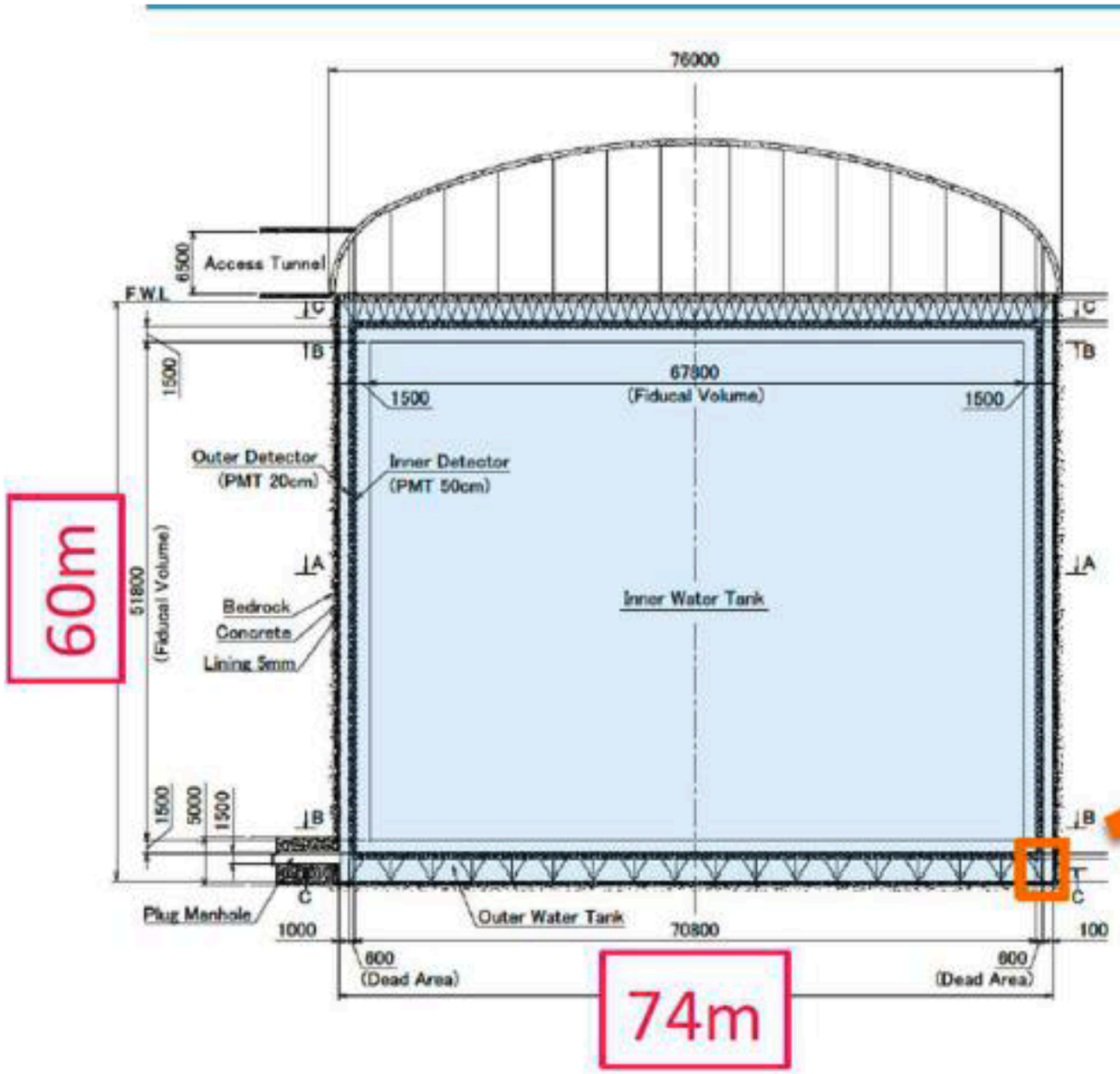
Route 41

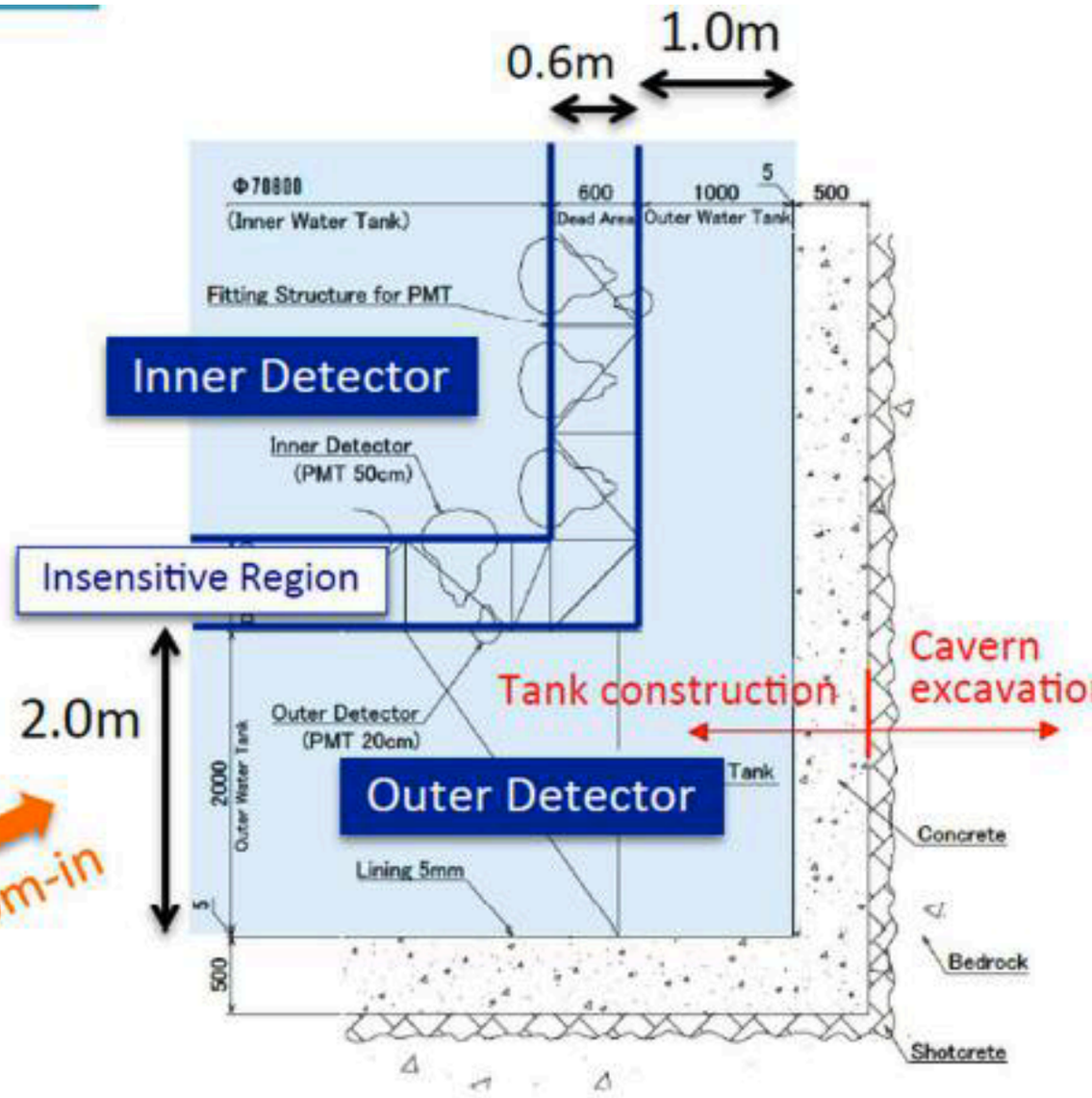
Kamioka Town

Funatsu Bridge

Google

Water tank





Total : 258.1 kt/tank

Inner Detector : 215.7 kt/tank

Fiducial Volume: 187.0 kt/tank

ID surface area : 20,063 m^2

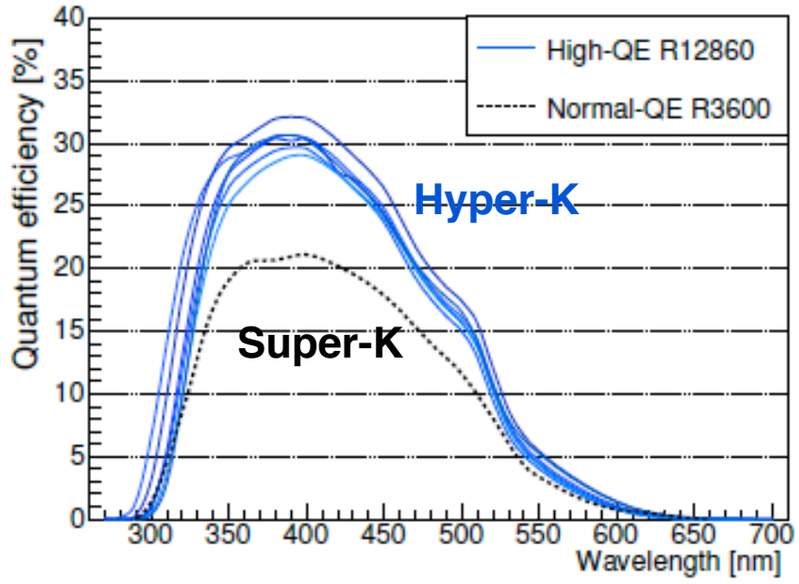
1 ID-PMT/0.5m^2 (40% coverage)

→ ~40,000 ID-PMTs/tank

~6,700 OD-PMTs/tank

Photosensors

Inner Detector



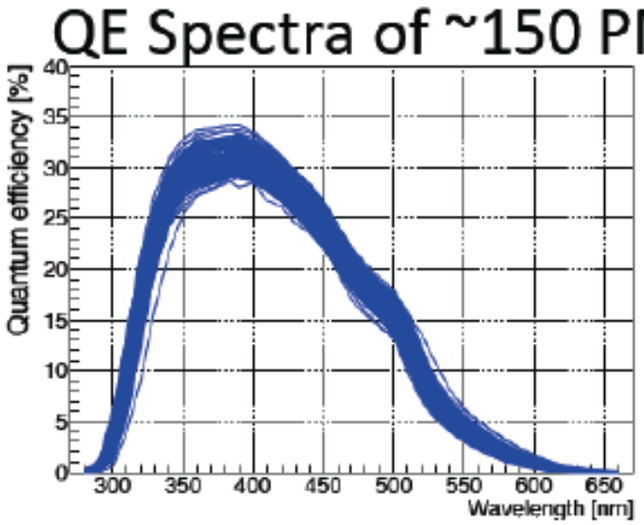
Outer Detector

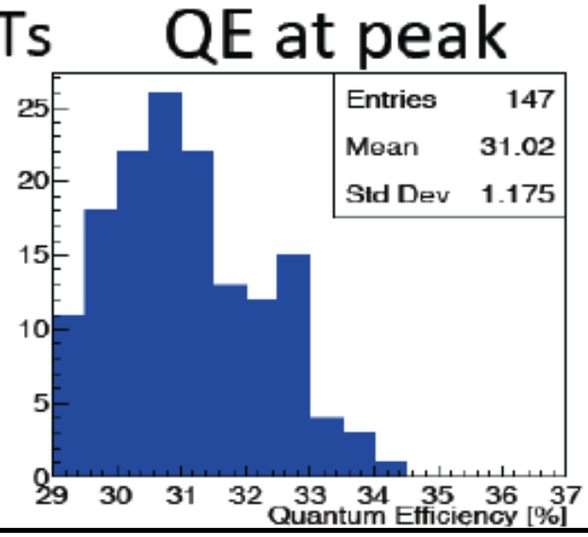
1 p.e. → time resolution 1.1ns
→ charge resolution 35%

Photosensor testing

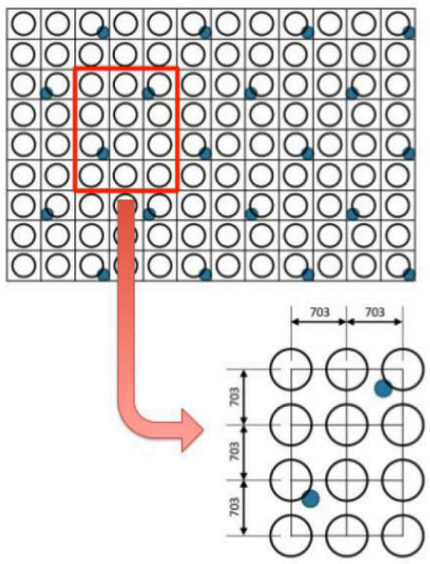
Y.Nishimura, talk at NEPTUNE2018

150 Box&Line 50 cm PMTs were manufactured
- all PMTs were tested at high pressure water ≤0.95 Mpa
- no damages were found





Box&Line



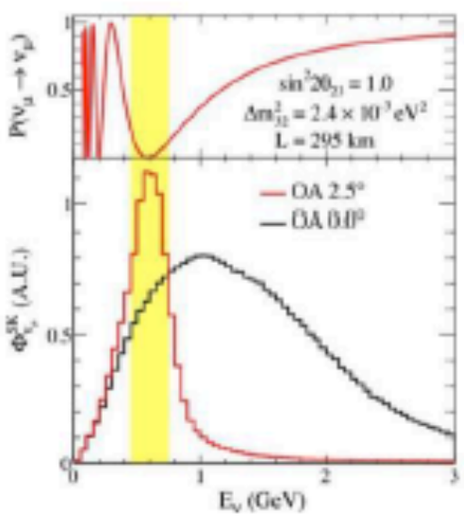
Alternative designs being discussed using multi-PMT modules, photon traps, …

Summary of Hyper-K parameters

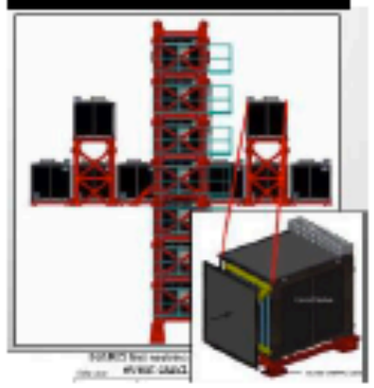
	Kamiokande	Super-K	Hyper-K
Depth	1,000 m	1,000 m	650 m
Dimensions of water tank			
diameter	15.6 m ϕ	39 m ϕ	74 m ϕ
height	16 m	42 m	60 m
Total volume	4.5 kton	50 kton	258 kton
Fiducial volume	0.68 kton	22.5 kton	187 kton
Outer detector thickness	$\sim$ 1.5 m	$\sim$ 2 m	1 $\sim$ 2 m
Number of PMTs			
inner detector (ID)	948 (50 cm ϕ)	11,129 (50 cm ϕ)	40,000 (50 cm ϕ)
outer detector (OD)	123 (50 cm ϕ)	1,885 (20 cm ϕ)	6,700 (20 cm ϕ)
Photo-sensitive coverage	20%	40%	40%
Single-photon detection efficiency of ID PMT	unknown	12%	24%
Single-photon timing resolution of ID PMT	$\sim$ 4 nsec	2-3 nsec	1 nsec

Tokai-to-Hyper-K Beam

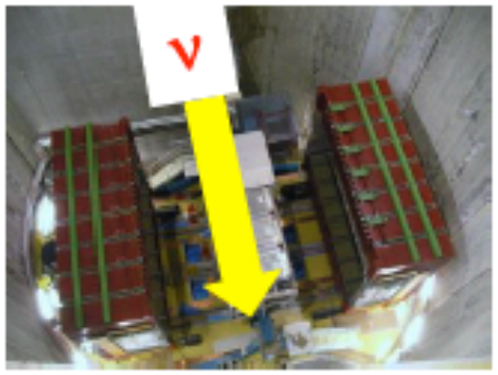
Off-axis neutrino beam



Neutrino monitor INGRID



Off-axis near neutrino detector



Near neutrino detector at 280 m from target

Decay tunnel

Horn

Target

Neutrino beam elements

J-PARC neutrino beam

2.5°off-axis, peak energy 600 MeV (oscillation maximum), current beam power 485 kW

Tokai-to-Hyper-K Beam

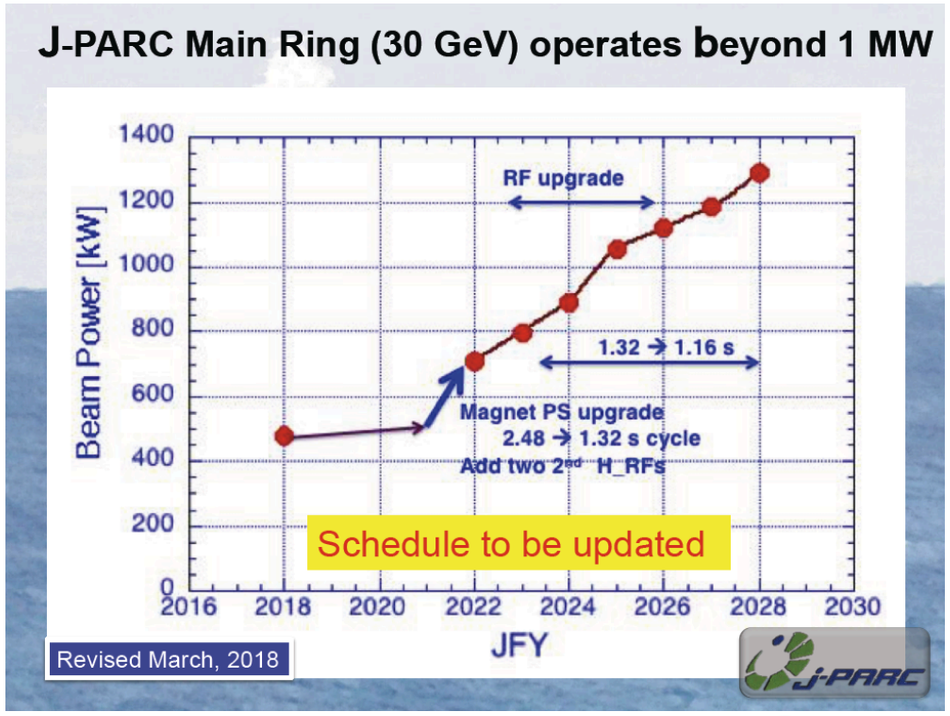
Power upgrade from ~0.5 to 1.3 MW

1st priority among projects which require new funding requests in KEK Project Implementation Plan (KEK-PIP)

- Increase repetition rate:
  Funding started
  - MR magnet power supply upgrade
  - MR RF upgrade (High grad/ PS)
  - MR Fast Extraction Kicker upgrade
- Higher #p/p (protons/pulse)
  - MR RF upgrade (PS)

Beam Power (kW)	485 (Achieved)	(940) +25%	1,300 (Goal for T2K-II)
#p/p(10^{12})	250	250	310
Rep T (s)	2.48	1.28	1.16

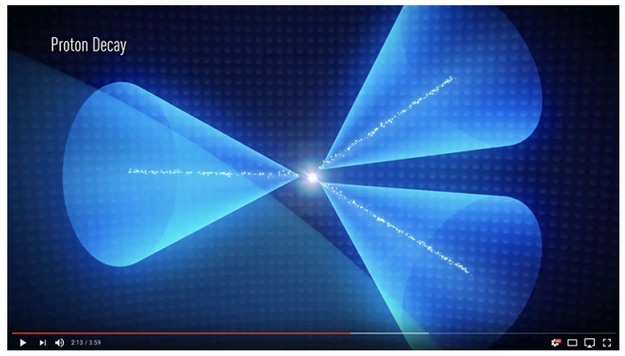
Funding started -10%

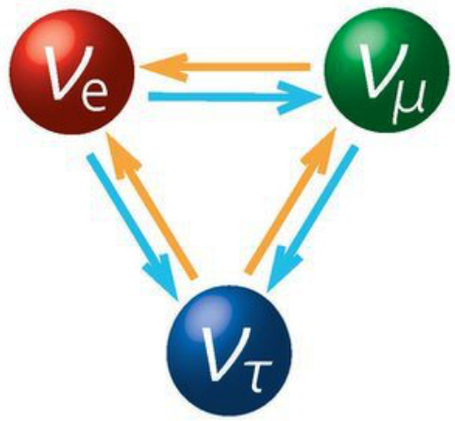


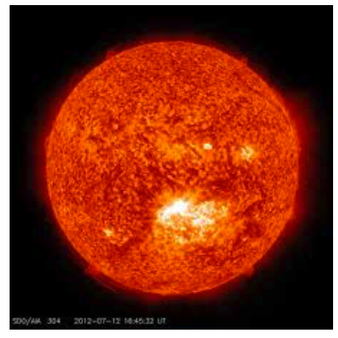
Hyper-K Science Program

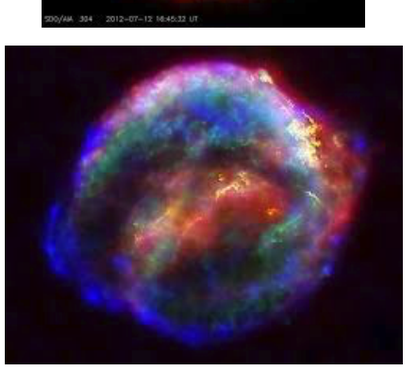
Hyper-K Science Program

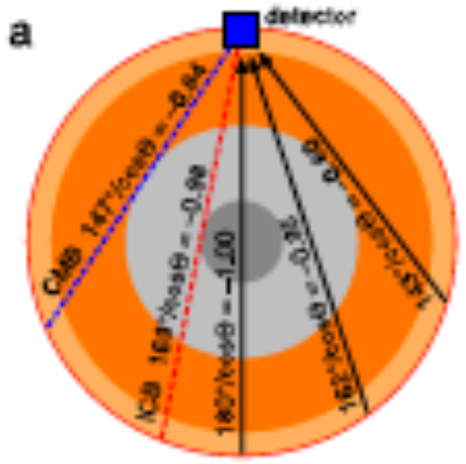
- Nucleon decays
- Comprehensive Neutrino Properties measurement program using Solar, Atm, and Accelerator ν's
  - $\theta_{12}, \theta_{23}, \theta_{13}, \Delta m^2_{21}, \Delta m^2_{32}, CP\delta$
- BSM Physics
  - Dark matter, …
- Neutrino astronomy and astrophysics
  - Supernova burst neutrinos
  - DSNB - Diffuse supernova neutrino background
- Earth Science
  - Earth tomography

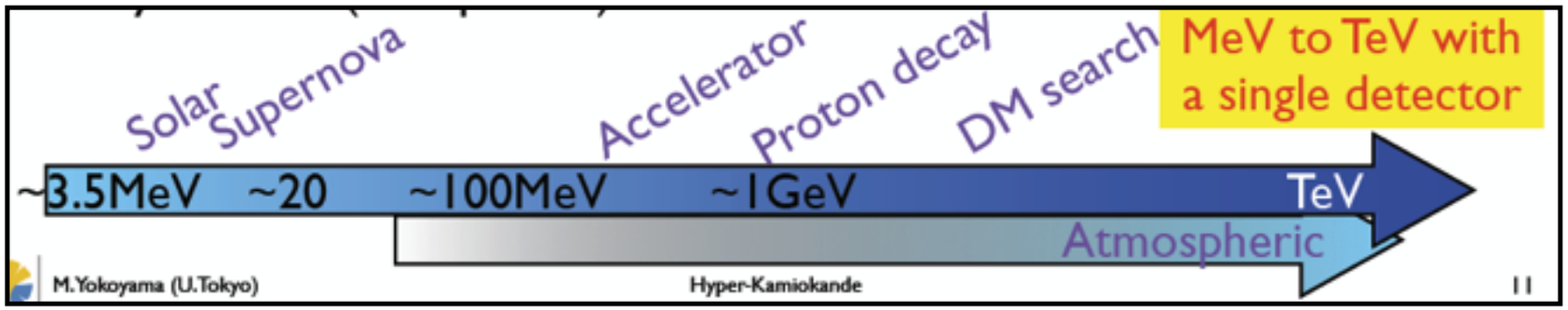








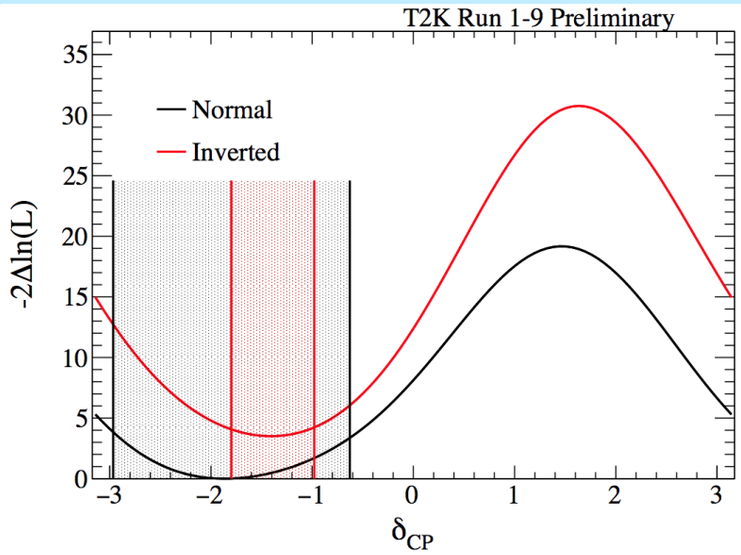




Accelerator Neutrinos

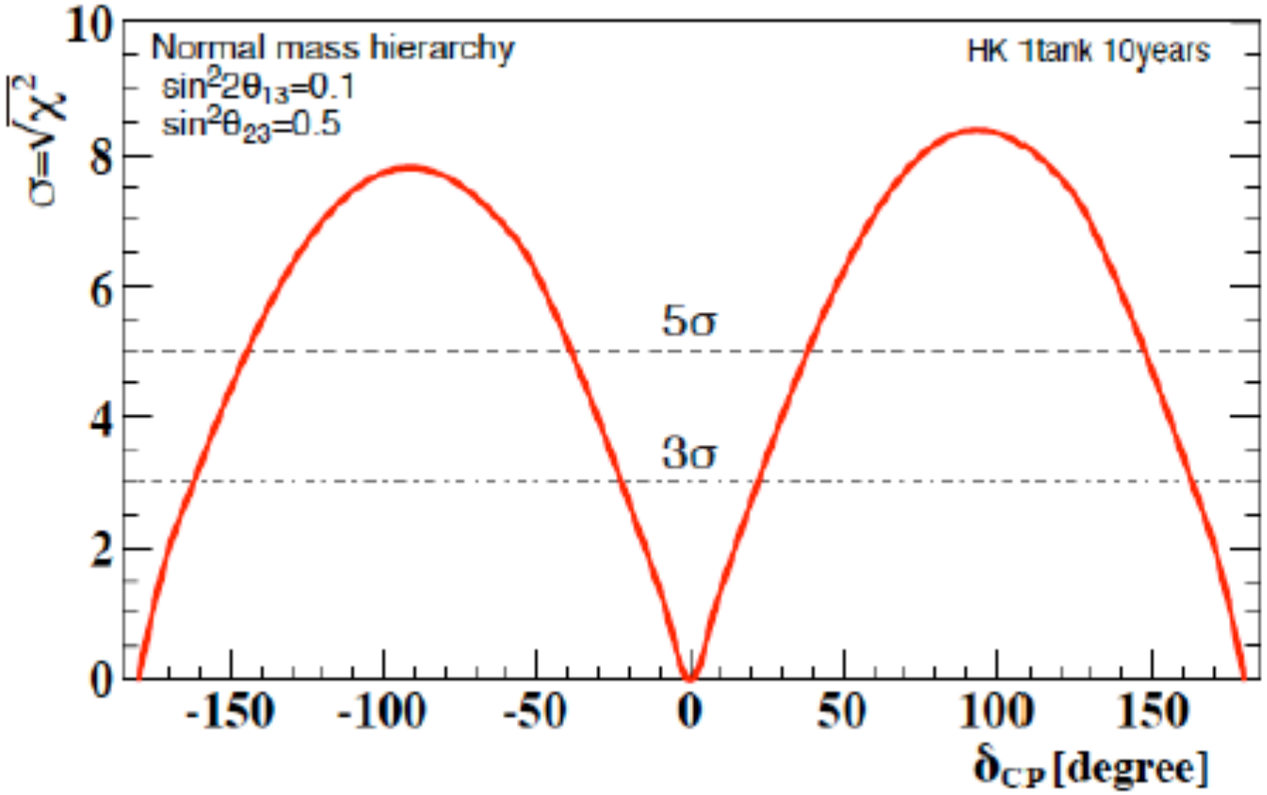
Accelerator Neutrinos

- T2K observed a hint of CP-violation
  - Current T2K statistics: 90 ν_e and 15 $\overline{\nu}_e$ candidates
- HK can study further with O(1000) $\nu_\mu \rightarrow \nu_e$ and $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ appearance events: ~3% statistical precision!
- Better control of systematics is crucial
  - Current T2K systematics: 6-7%
  - Upgraded near-detector and new intermediate detector to constrain flux+interaction systematics to <4%
- A second detector in Korea would significantly enhance the sensitivity



Hyper-K CP sensitivity

Integrated beam power 1.3 MW x 10^8 s
→ 2.7 x 10^{22} POT with 30 GeV proton beam
$\nu : \bar{\nu} = 1:3$ $\sin^2 2\theta_{13} = 0.1$



Hyper-K: uncertainties of expected number events

$\nu_\mu \to \nu_e$	3.2%
$\nu_\mu \to \nu_\mu$	3.6%
$\bar{\nu}_\mu \to \bar{\nu}_e$	3.9%
$\bar{\nu}_\mu \to \bar{\nu}_\mu$	3.6%

T2K systematic uncertainties 5-6 %

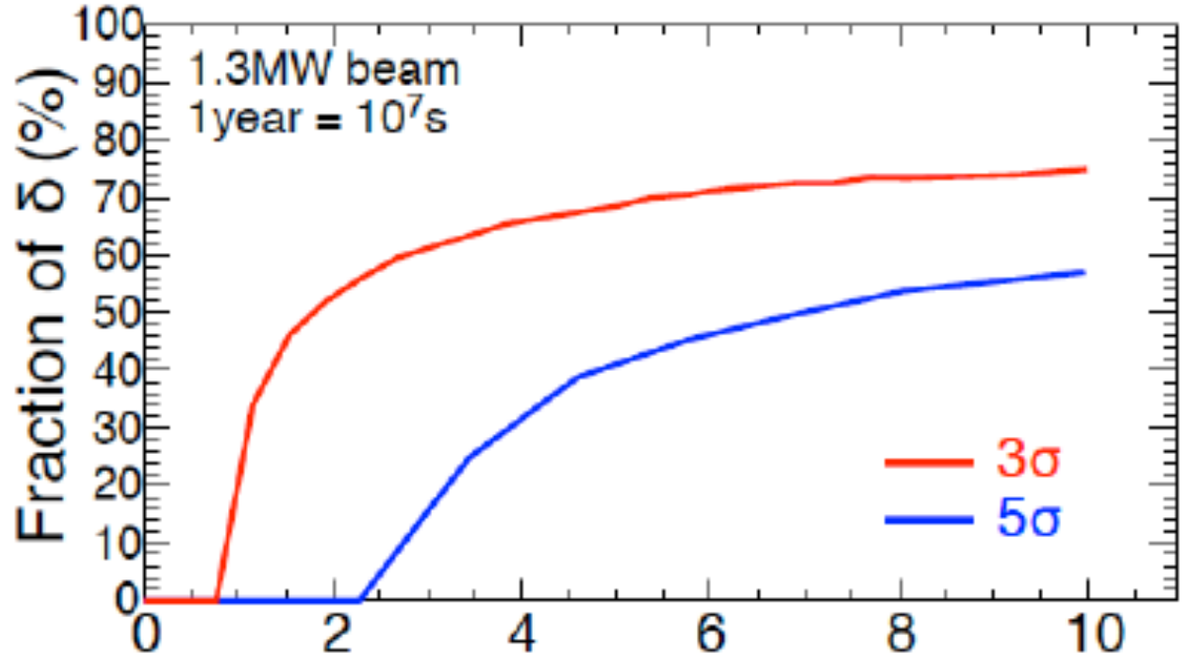
Exclusion of δ=0 at 8σ (for δ= -π/2)
5σ (3σ) significance for 57 (80)% of possible δ values

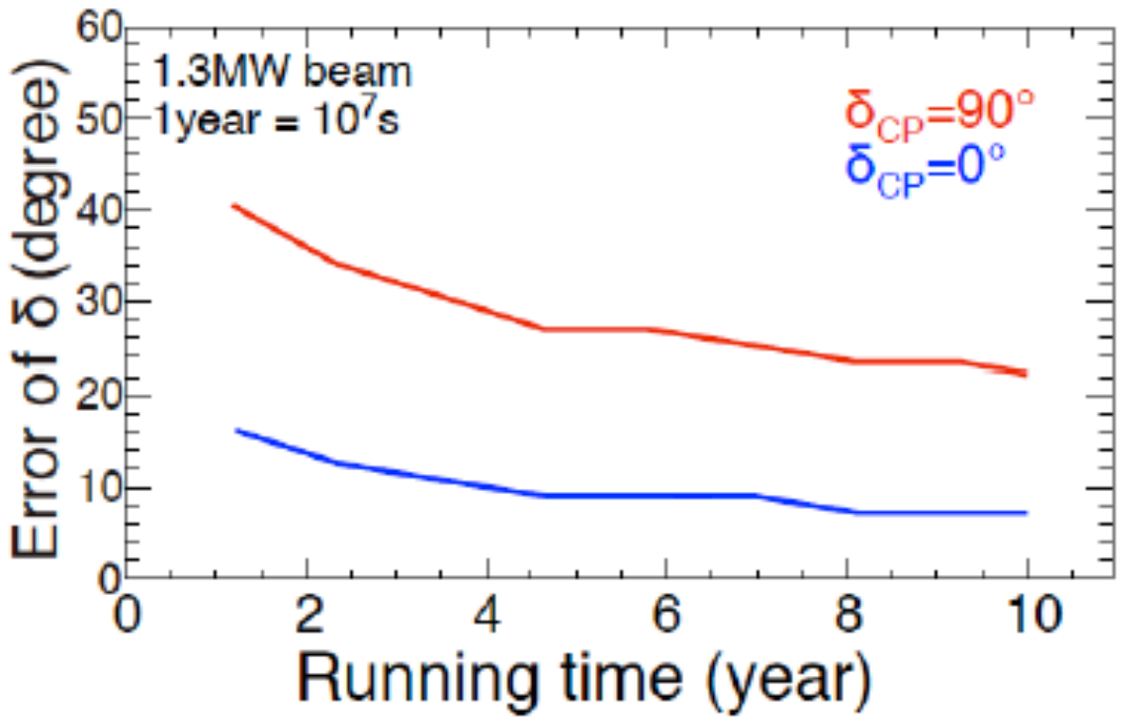
Hyper-K CP sensitivity

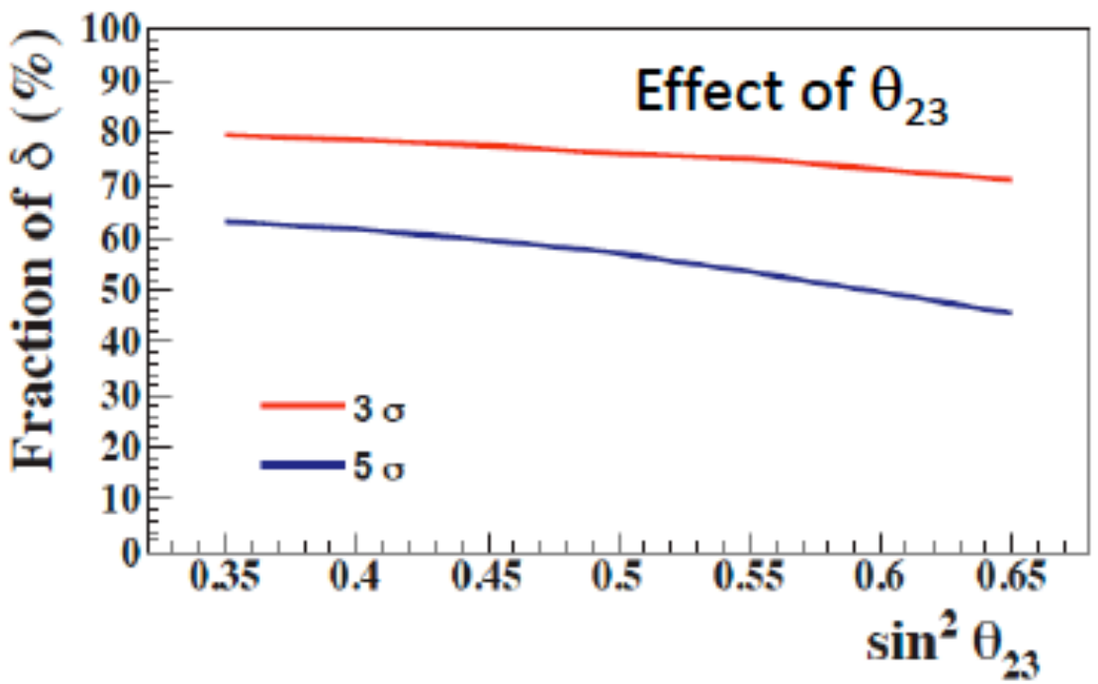
Measurement of δ

δ = 90 deg σ = 23 deg

δ = 0 deg σ = 7 deg







CPV Global Picture

arXiv:1805.04163

Hyper-K
- Single tank
- Normal hierarchy
- Systematics 3-4%

$\nu : \bar{\nu} = 1 : 3$

- CPV (δ = -90 deg, 5σ)
  → 1.3MW x 4 years

arXiv:1807.10334

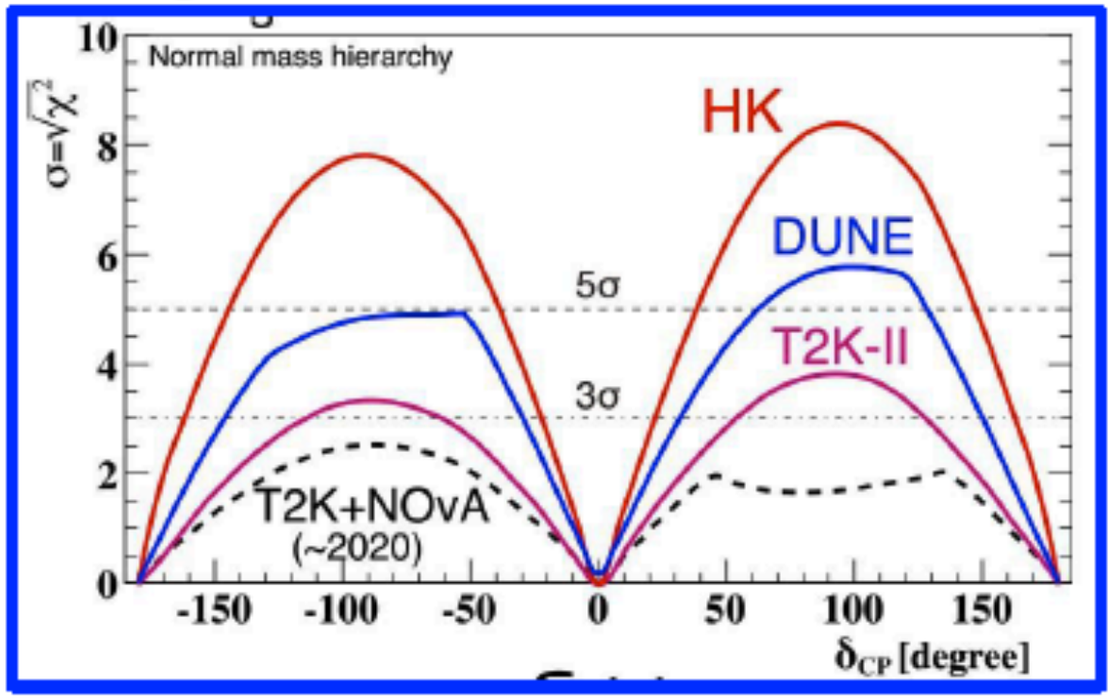
DUNE
- Staging plan
- Normal hierarchy

$\nu : \bar{\nu} = 50\% : 50\%$

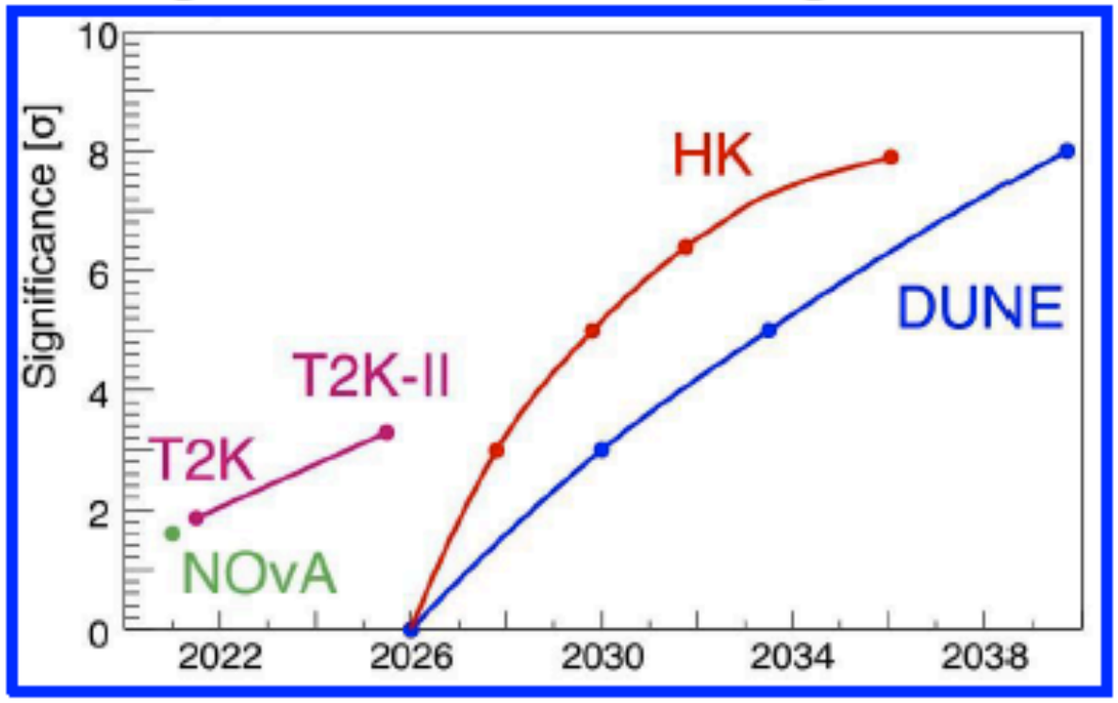
- CPV (δ = -90 deg, 5σ) 253 kt·MW·year
  → 6.5 years

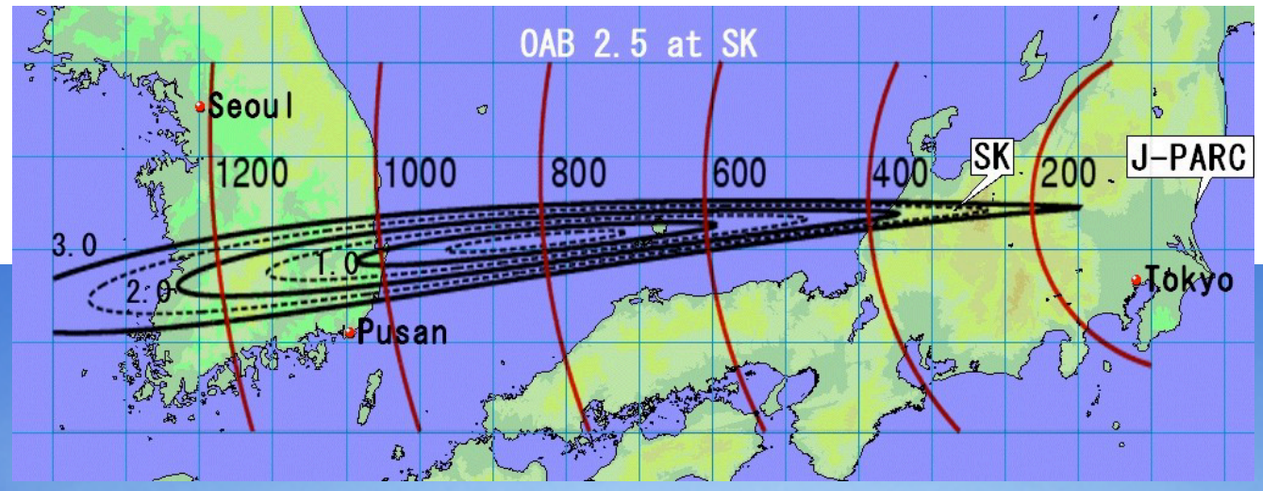
Combination T2K-II and NOvA can reach ~4.5σ for δ = -90 deg by 2026

Significance for δ = 0 exclusion



Significance for δ = -90 deg

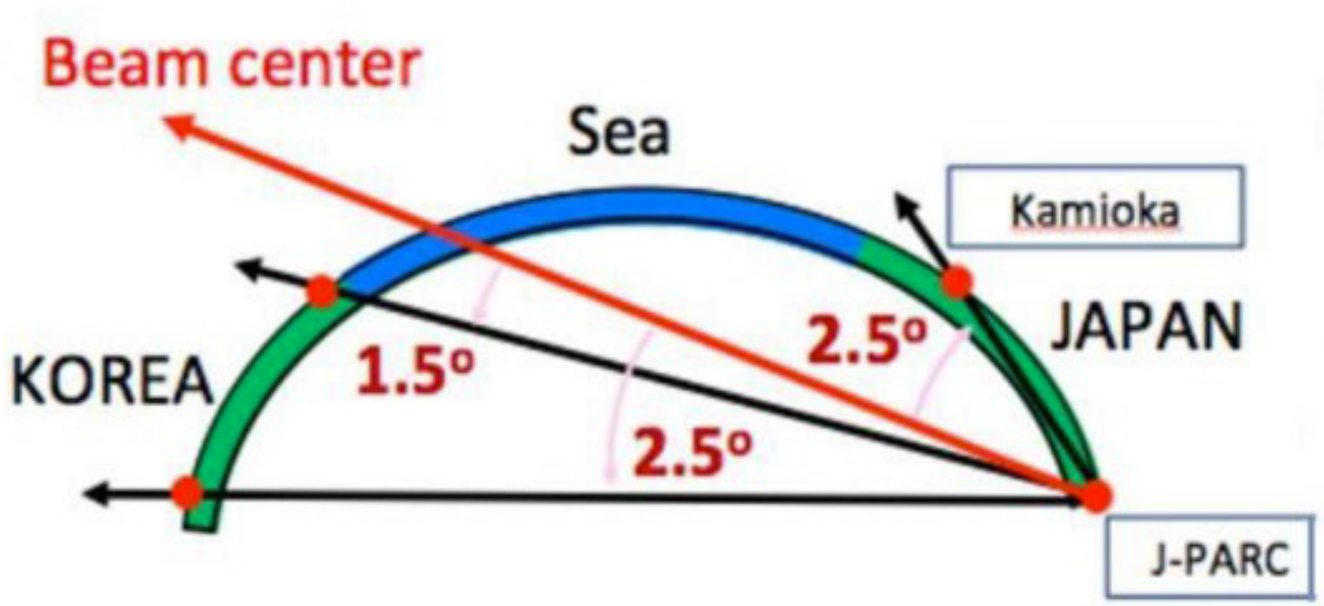


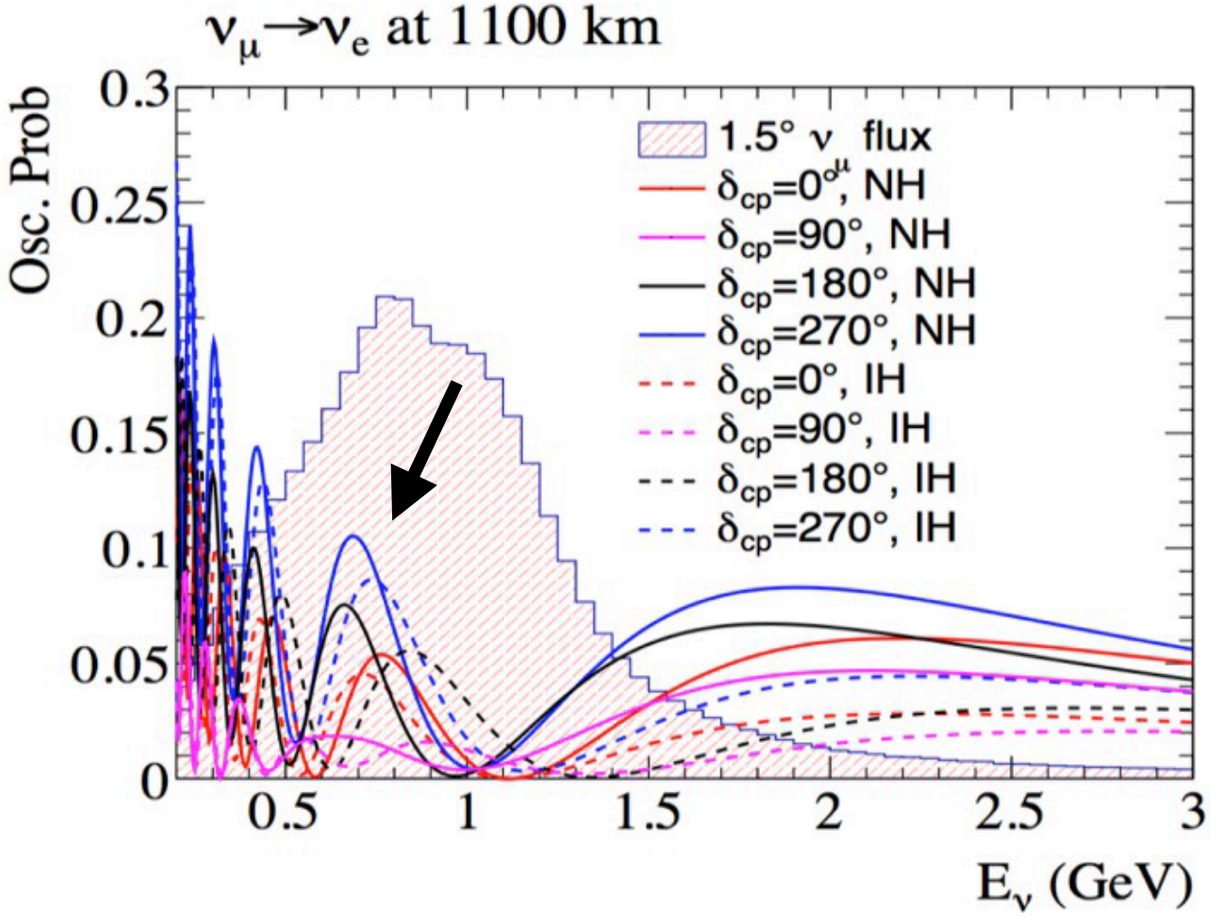


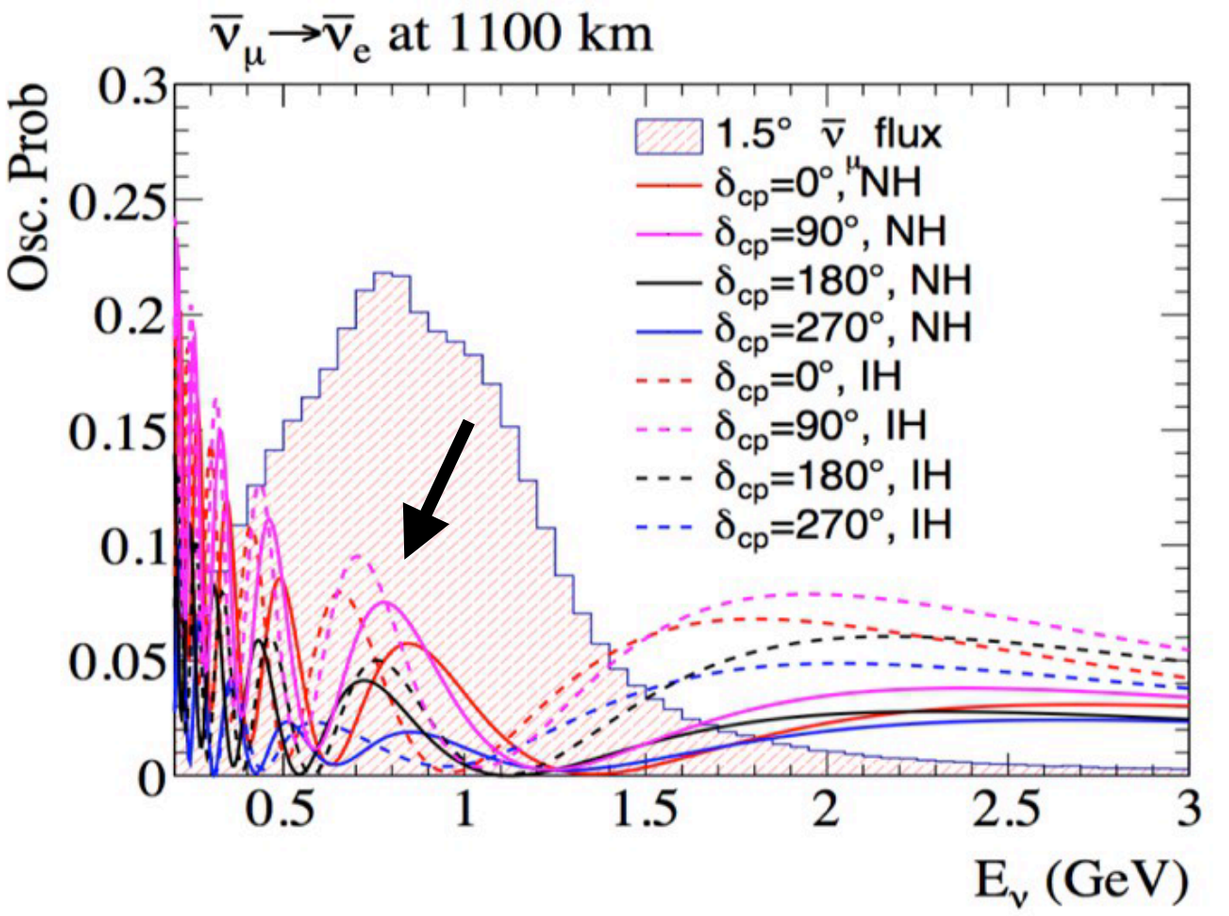
2nd Detector in Korea

2nd tank in Korea

- 2nd oscillation maximum covered
  - CP asymmetry for ν_e/ν_e appearance is 3x larger than at 1st maximum
  - larger CP effect → less sensitive to systematic errors
- Larger matter effect for longer baseline
  - Results in improved sensitivity for mass hierarchy, however smaller number of events because of flux reduction

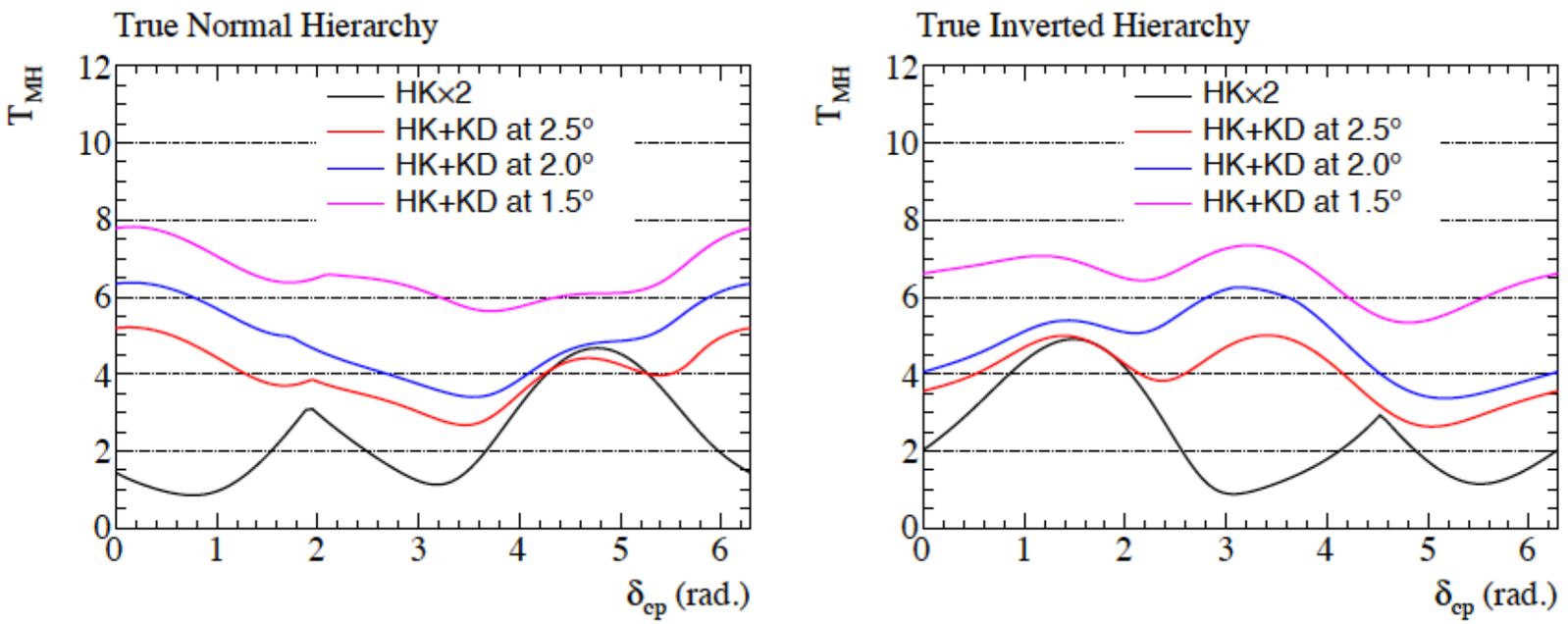




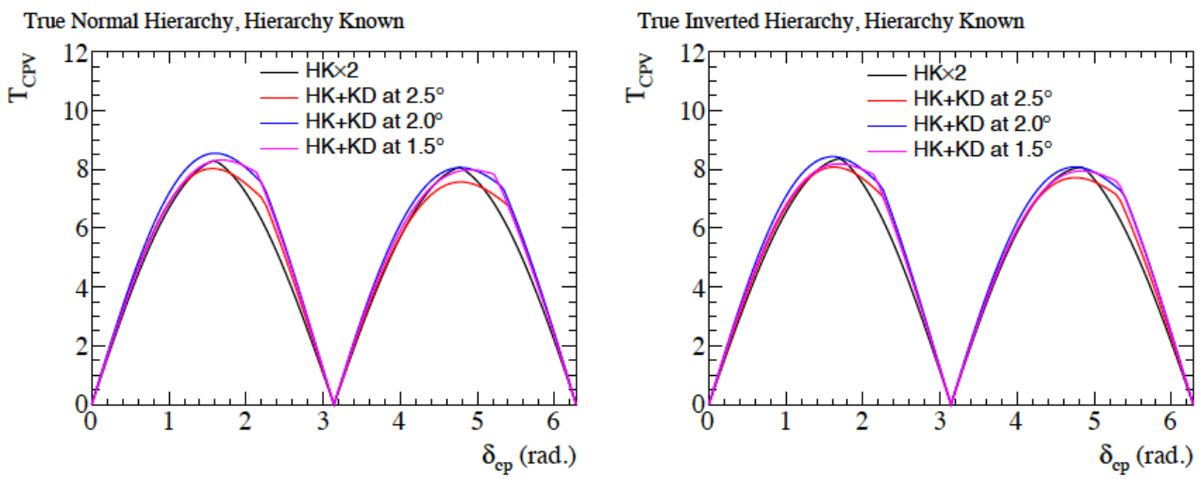


2nd tank in Korea

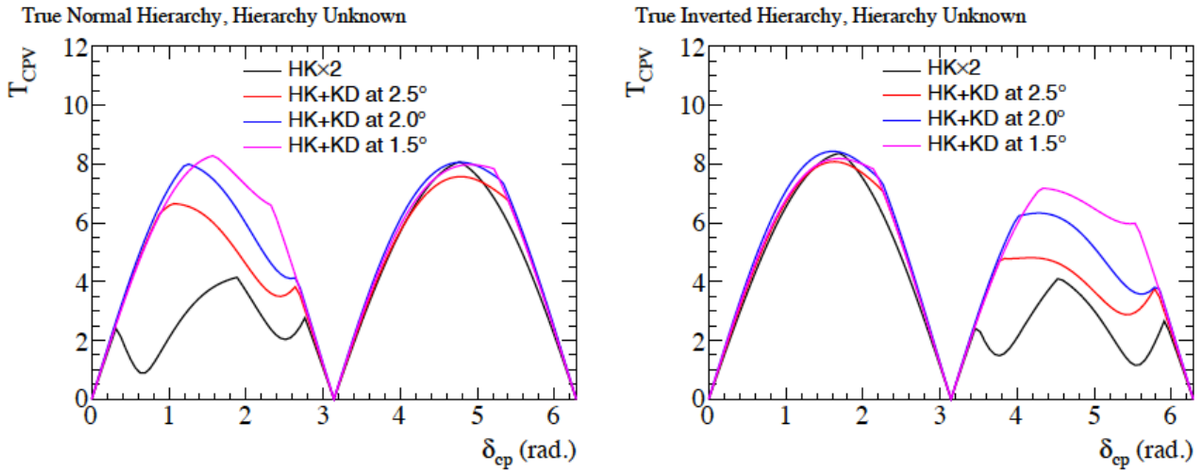
- Improved sensitivity to mass hierarchy 6-8σ (true NH) 5.5-7σ (true IH) for all δ_{CP}



CP violation
– known hierarchy



– unknown hierarchy

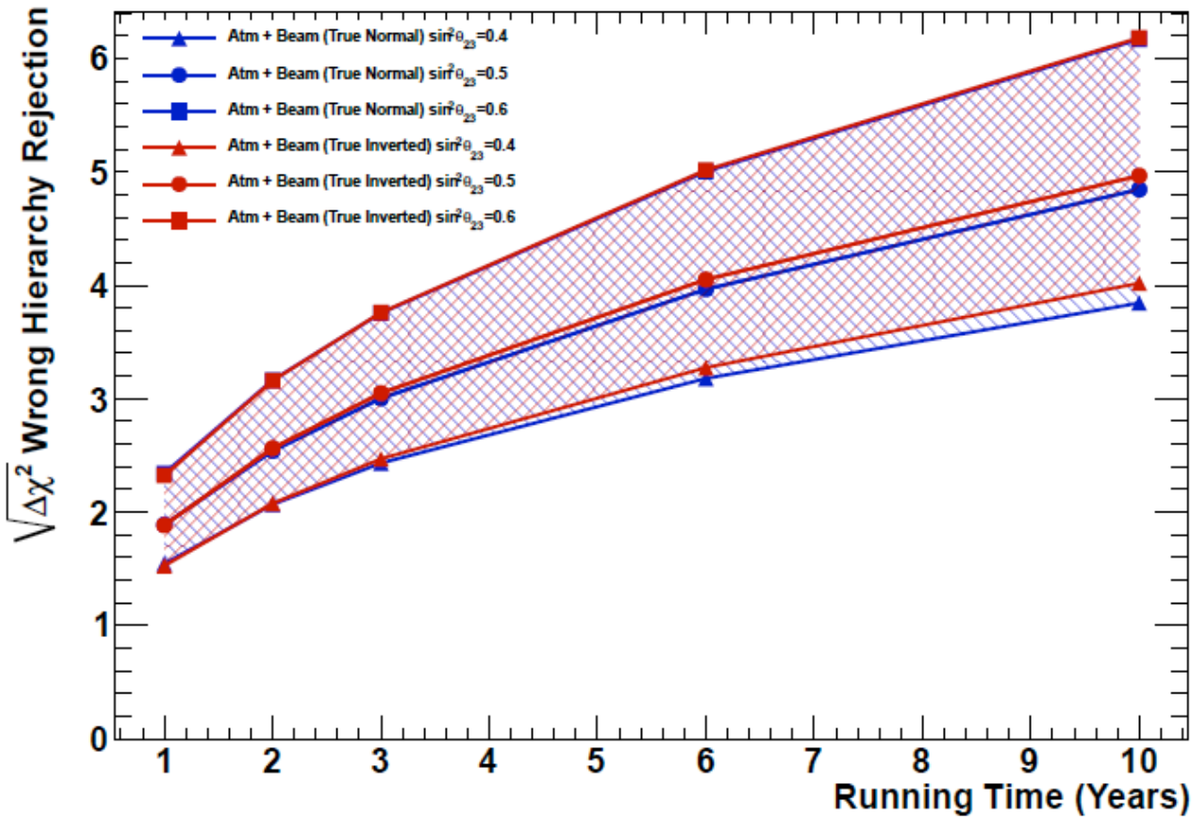


Neutrino Oscillations (Atmospheric Neutrinos)

Atmospheric Neutrinos

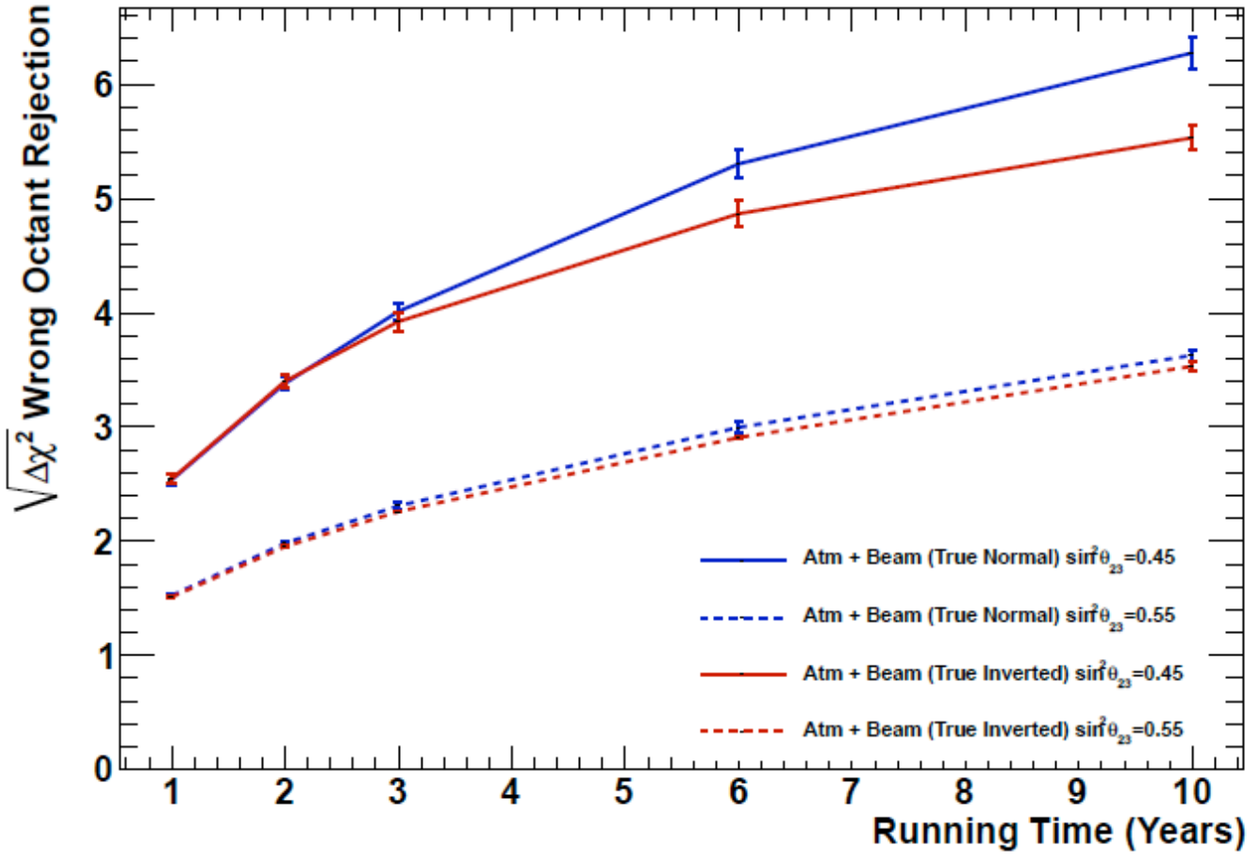
Joint analysis of atmospheric and accelerator neutrinos

Sensitivity to mass hierarchy

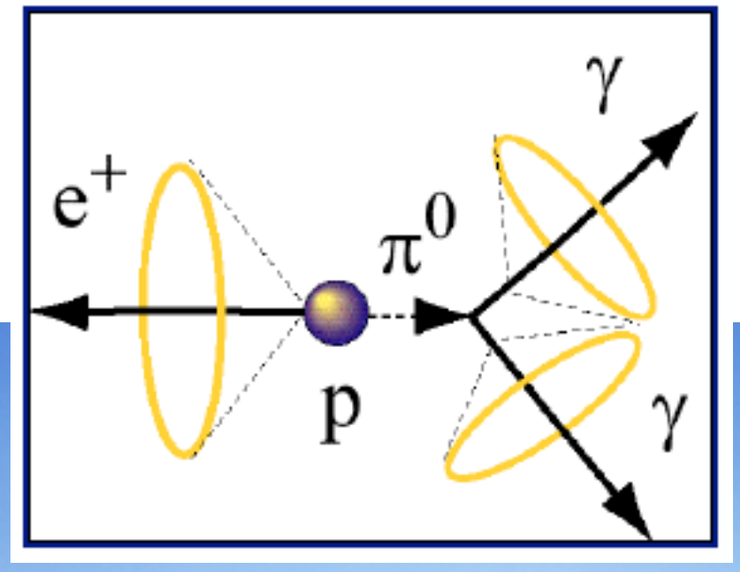


1 Hyper-K tank 3σ rejection of wrong hierarchy with 10 year data

Octant sensitivity



1 Hyper-K tank
can resolve octant at 3σ,
for $|45^0 - \theta_{23}| \geq 2.3$ deg

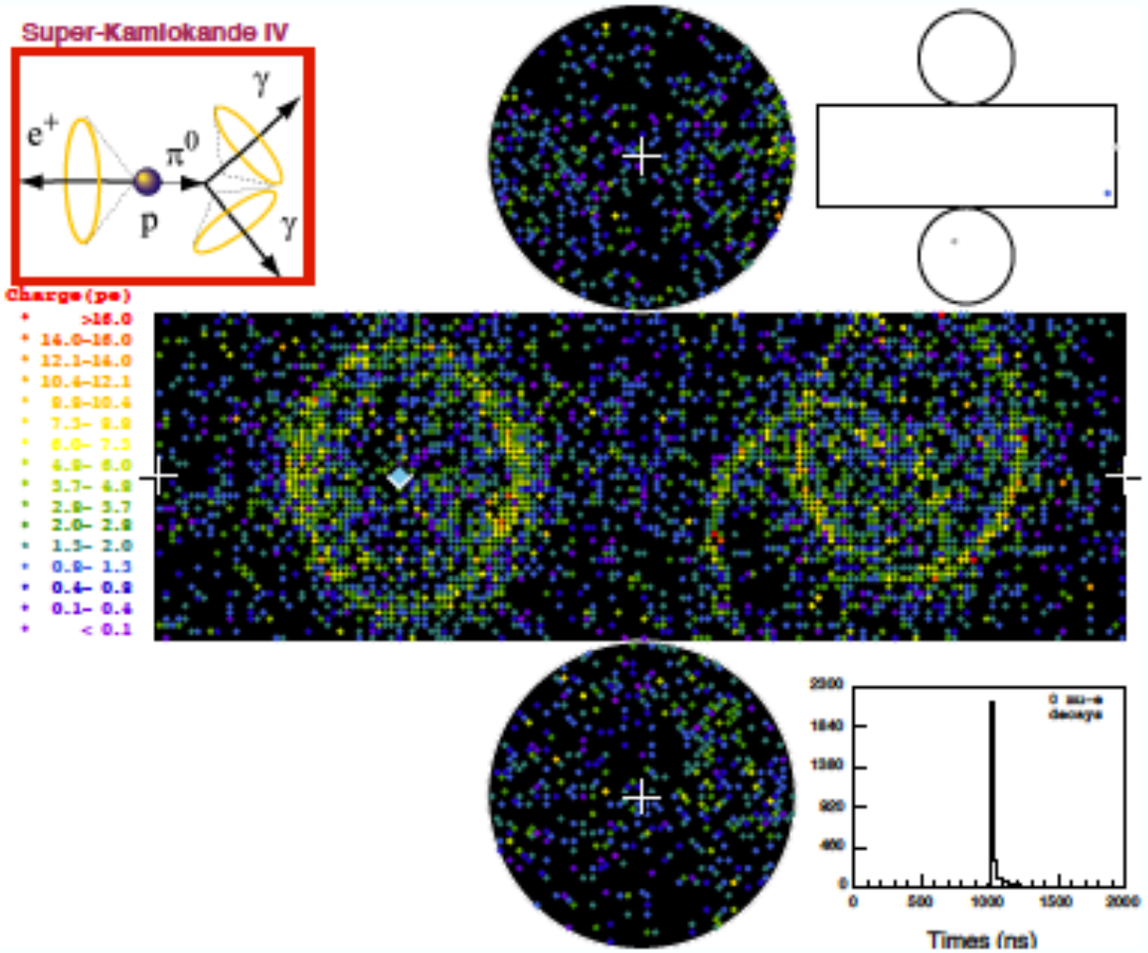


Nucleon decay

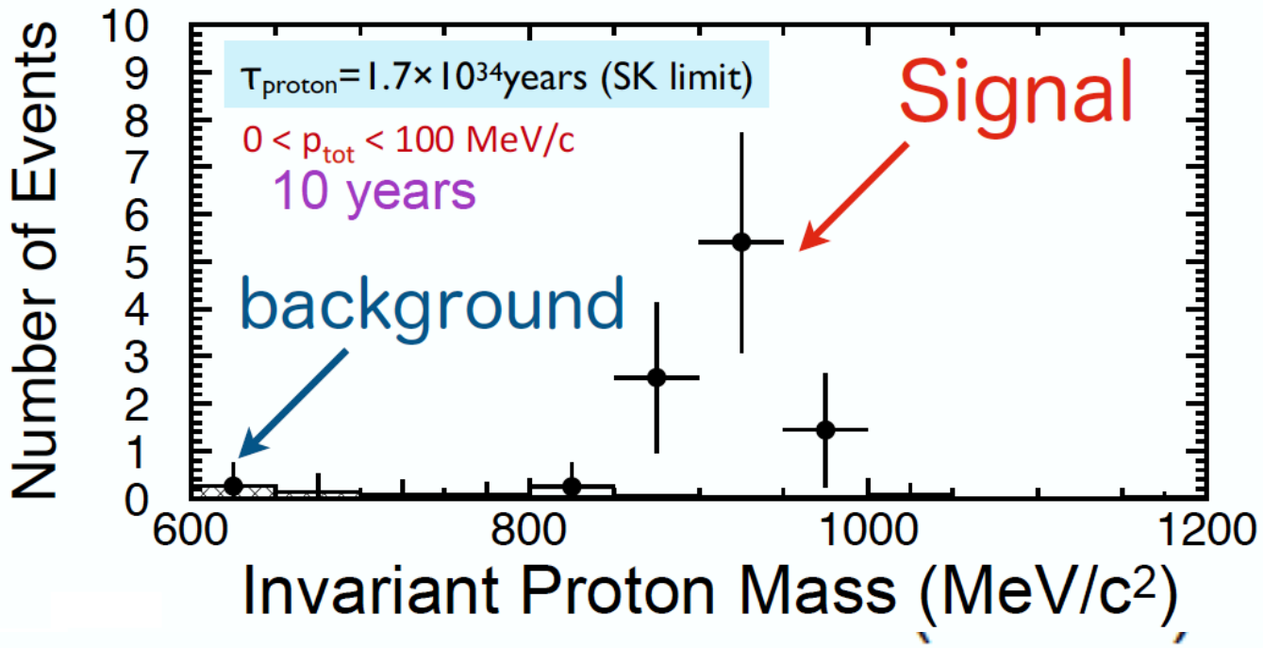
Nucleon Decay

World-leading searches from Super-K to Hyper-K

Cherenkov ring image in Super-K



Expected signal for $p \rightarrow e\pi^0$ channel

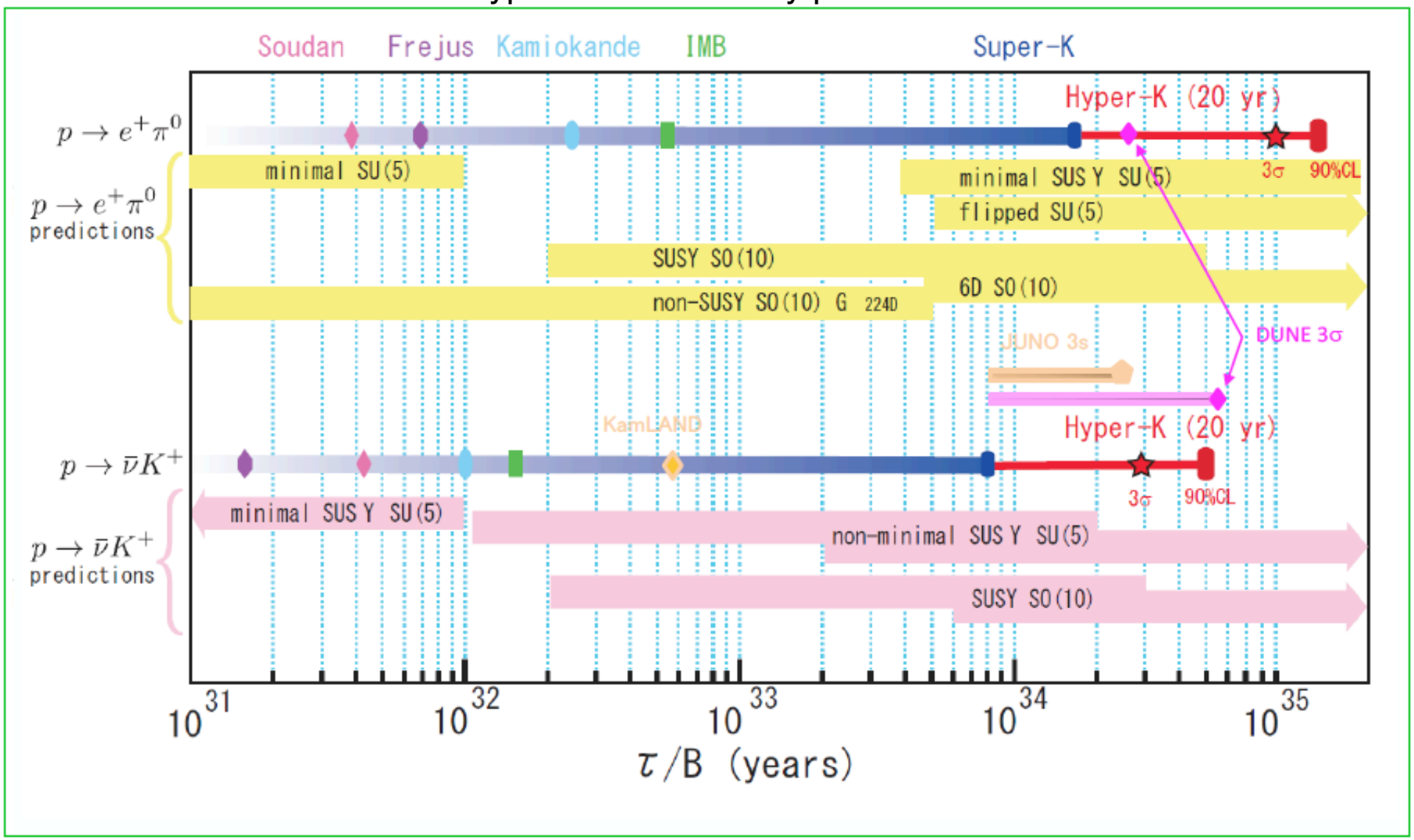


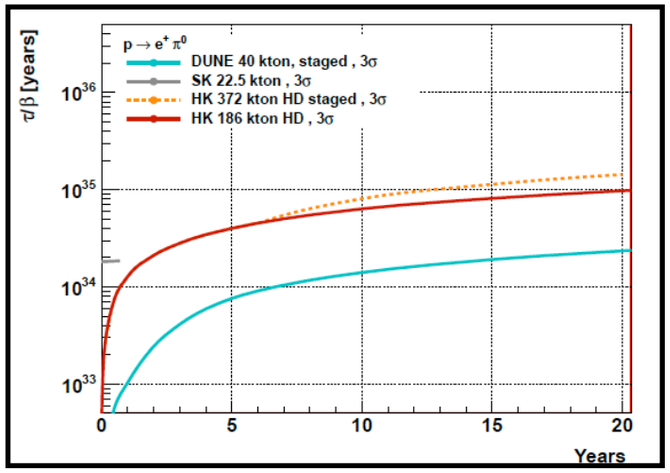
3σ reach to 10^{35} yrs

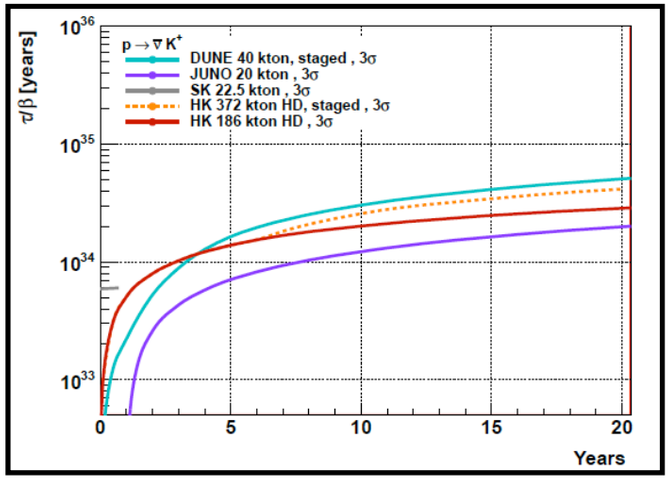
Neutron tagging is a key to further reduce the atmospheric neutrino backgrounds

Nucleon Decay

Hyper-K 3σ discovery potential







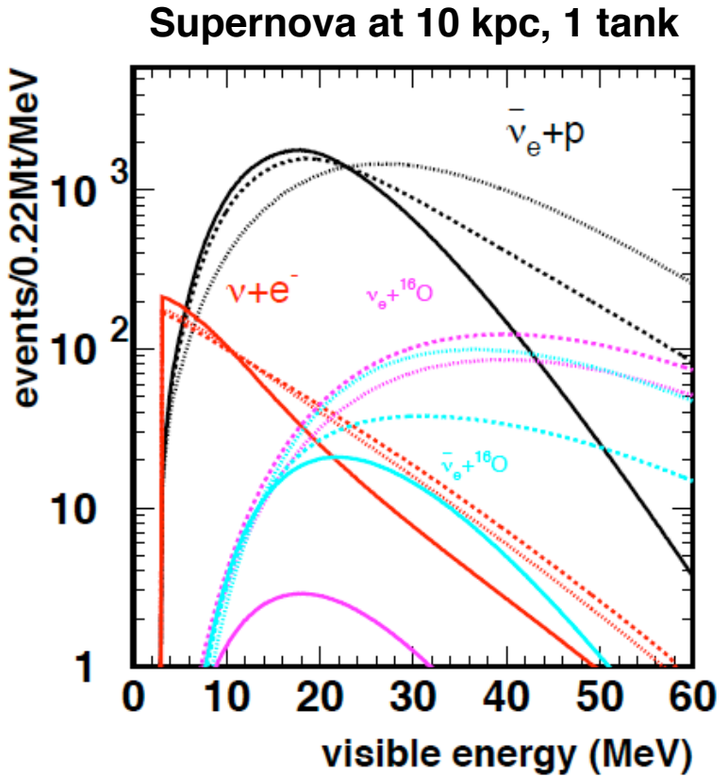
	material	Fiducial Mass (kton)
Super-K	Water	22
Hyper-K	Water	**190**
Dune	Argon	40
JUNO	Liq. Scinti	20

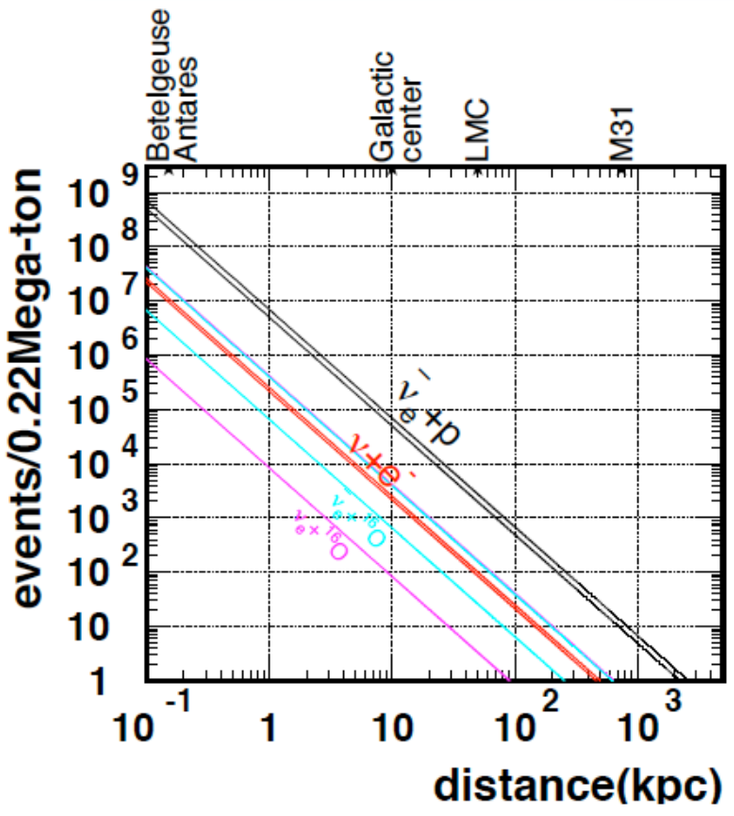
- Proton decay discovery potential for many decay mode
  - **$p \to e^+\pi^0$; 1×10^{35} yrs with 3σ CL**
  - **$p \to \nu K^+$; 3×10^{34} yrs**

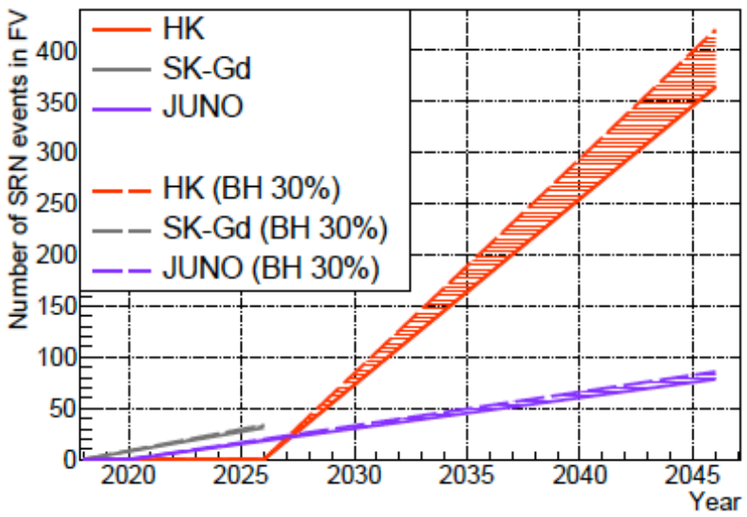
Supernova Neutrinos

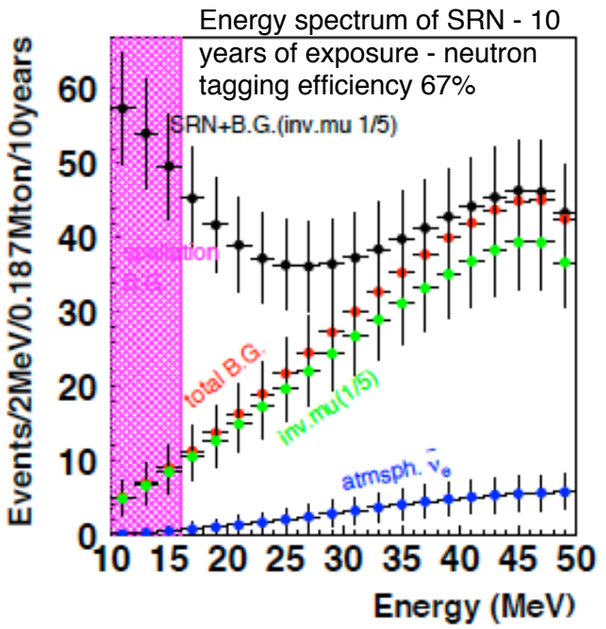
Supernova Neutrinos

- **Supernova burst**
  - Sensitive to SNe in Andromeda
  - 50-80 k events / SN @10 kpc
  - Time and energy profile with high statistics
    - Explore dynamics of SN central engine
      - Explosion mechanism, NS/BH formation
  - 1° pointing for SN alerts - Multi-messenger (Optical, GW, …)
- **DSNB - Diffuse Supernova ν**
  - Super-K-Gd expected to observe first
  - HK will measure the spectrum
    - History of star/BH formation





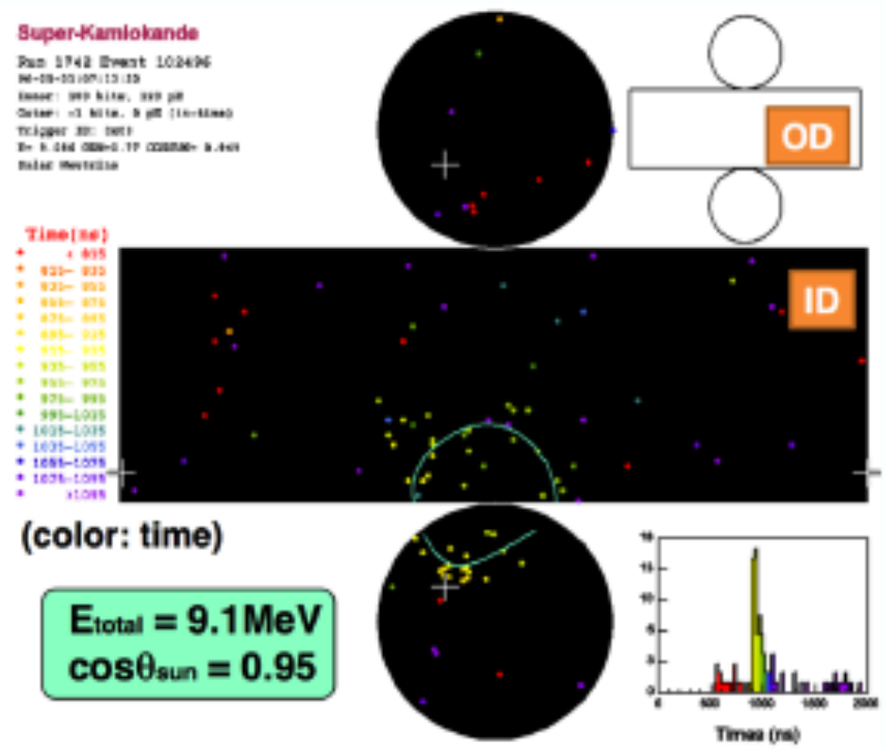


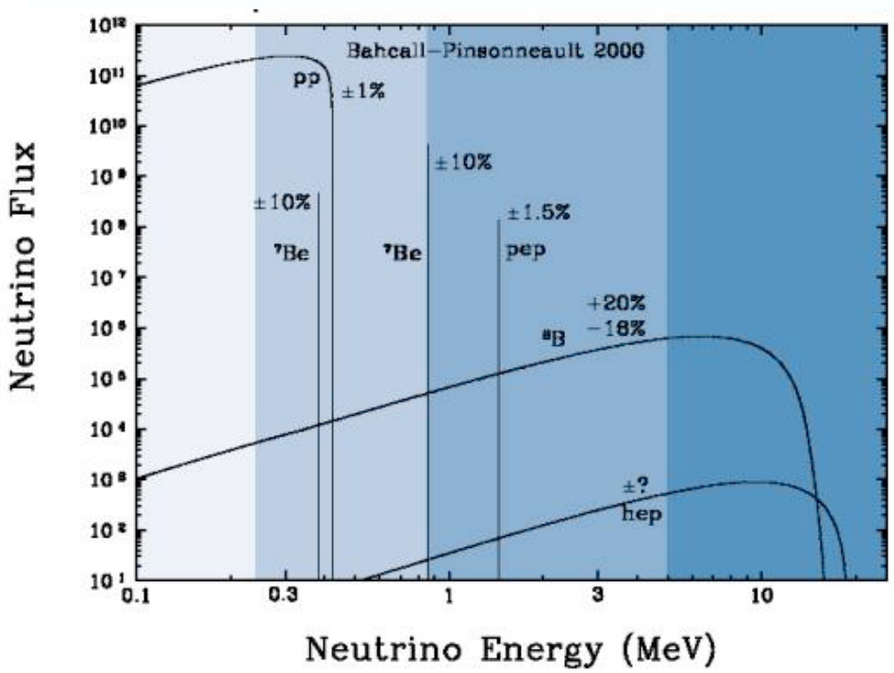


Solar Neutrinos

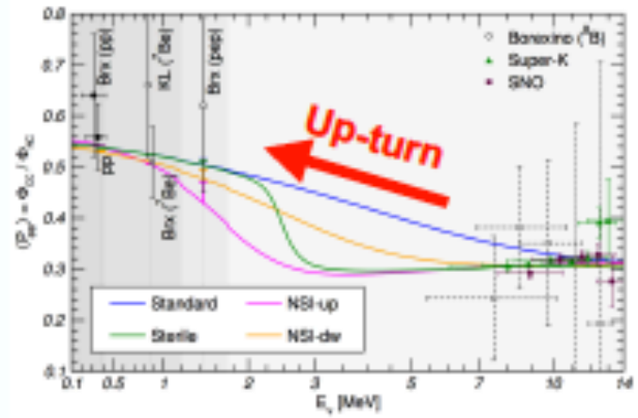
Solar Neutrinos

Cherenkov ring image in Super-K





survival probability of electron solar neutrinos



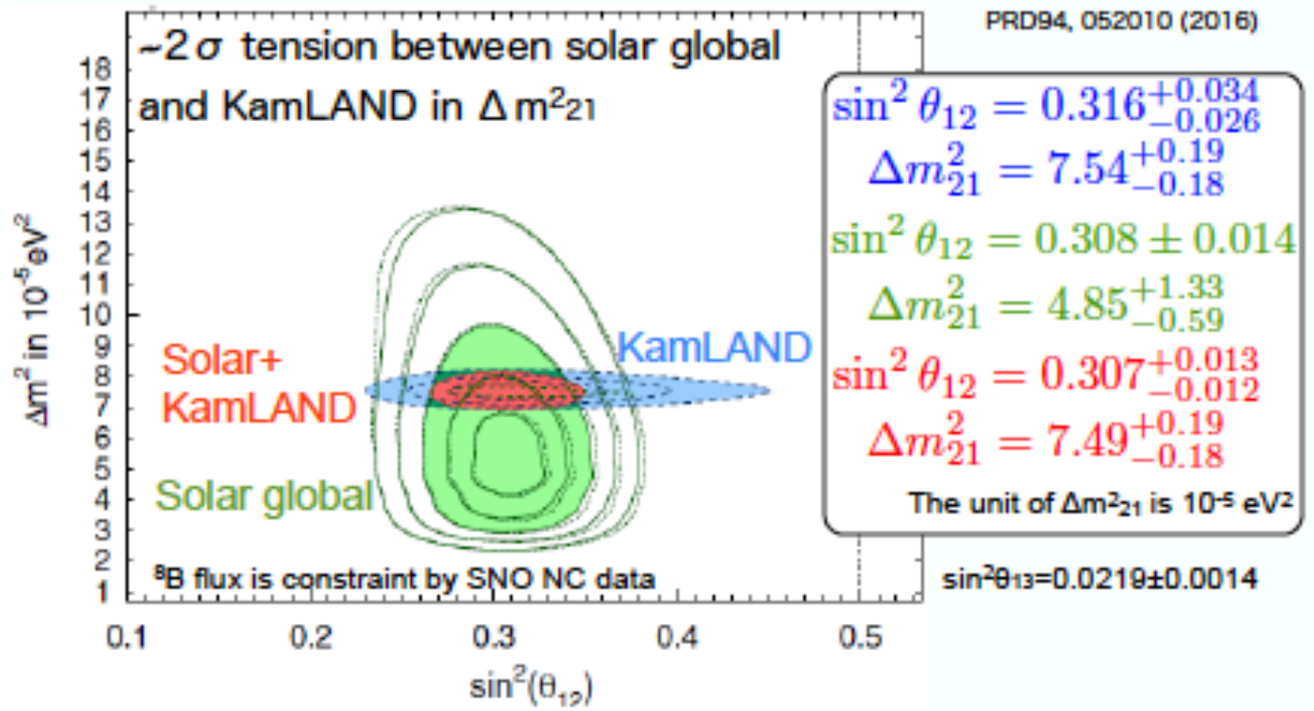
- **Neutrino oscillation study**
  - Precision measurements of spectrum and day/night flux asymmetry (test of standard matter effect or exotic scenario?)
- **Solar physics**
  - First observation of Hep ($^3He+p \rightarrow {}^4He+e^{+}+\nu_e$) neutrinos

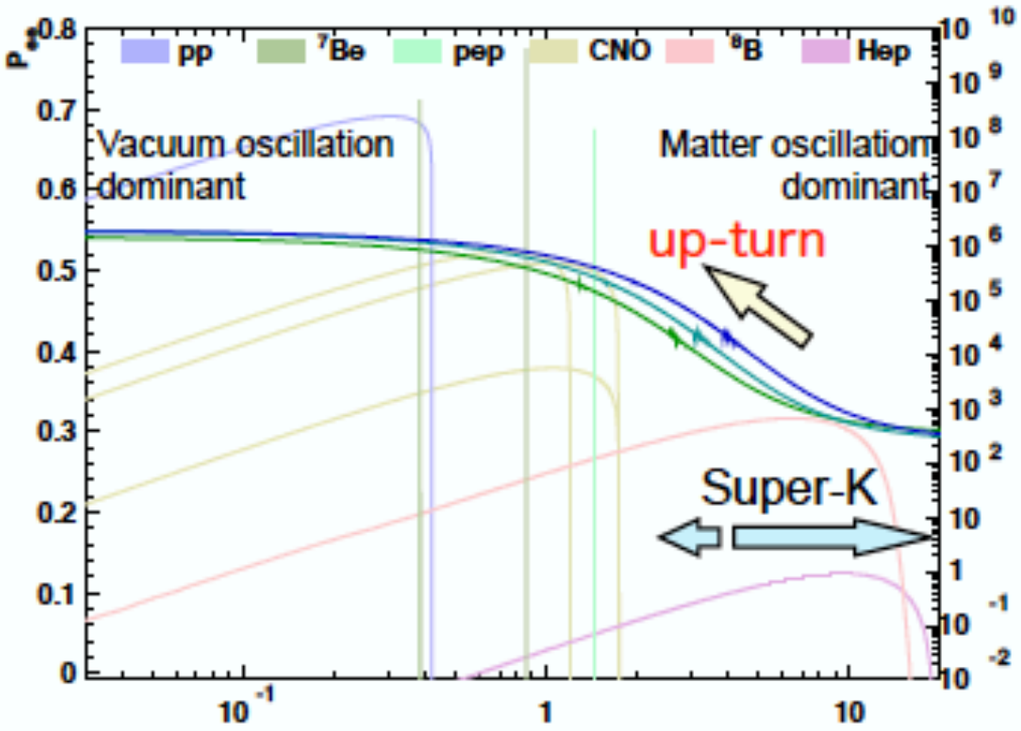
⇒ Low energy threshold,

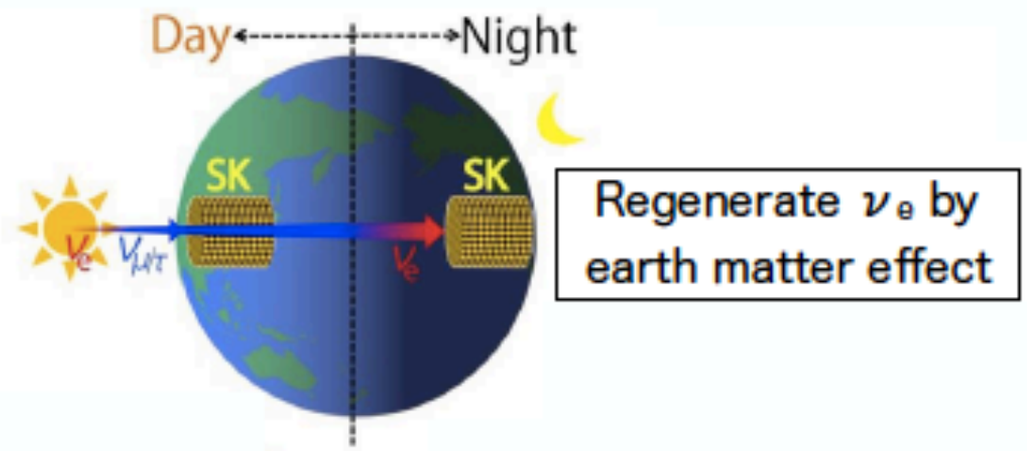
high resolution reconstruction, and low background are critical

Solar Neutrinos

- Unresolved tension between solar and reactor (KamLAND) Δm^2_{21} values
- Super-K's sensitivity to Δm^2_{21} come from spectrum distortion around a few MeV and day-night flux asymmetry
- Hyper-K can independently test this tension with much higher statistics

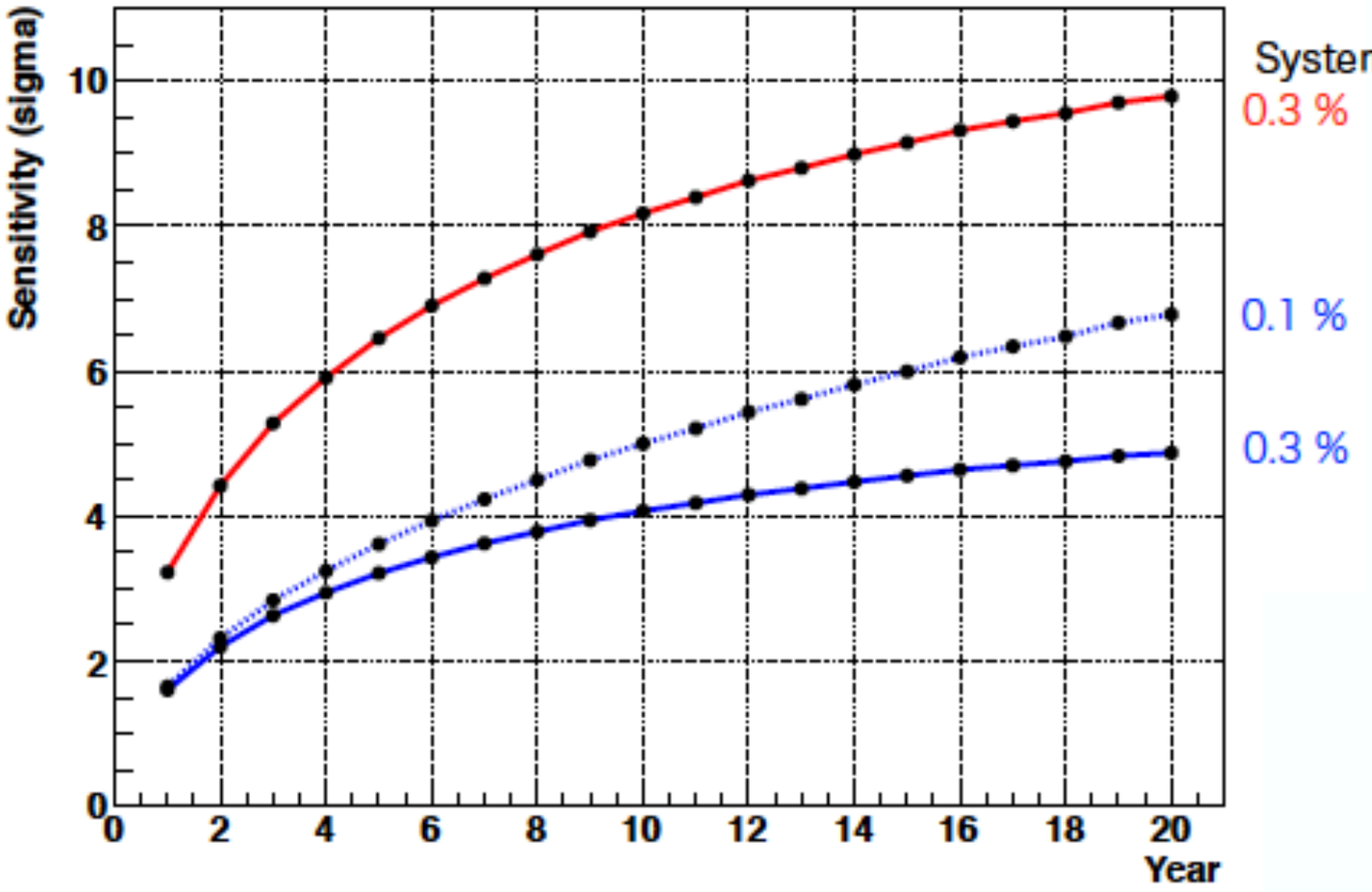


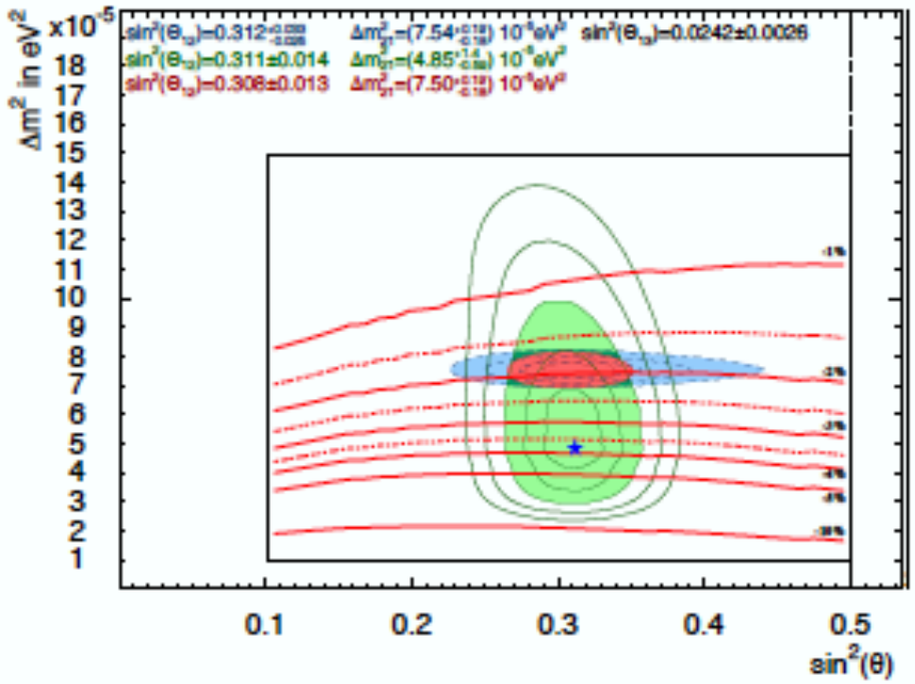




Solar neutrino day/night sensitivity

- Significance for non-zero day/night asymmetry with current solar Δm^2_{21}
- Significance to distinguish current solar and KamLAND Δm^2_{21}



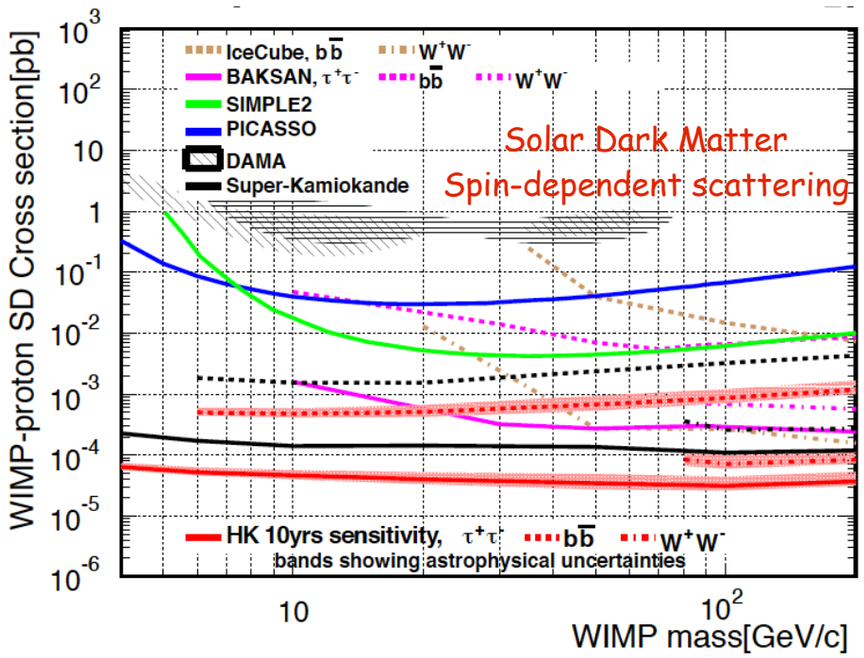


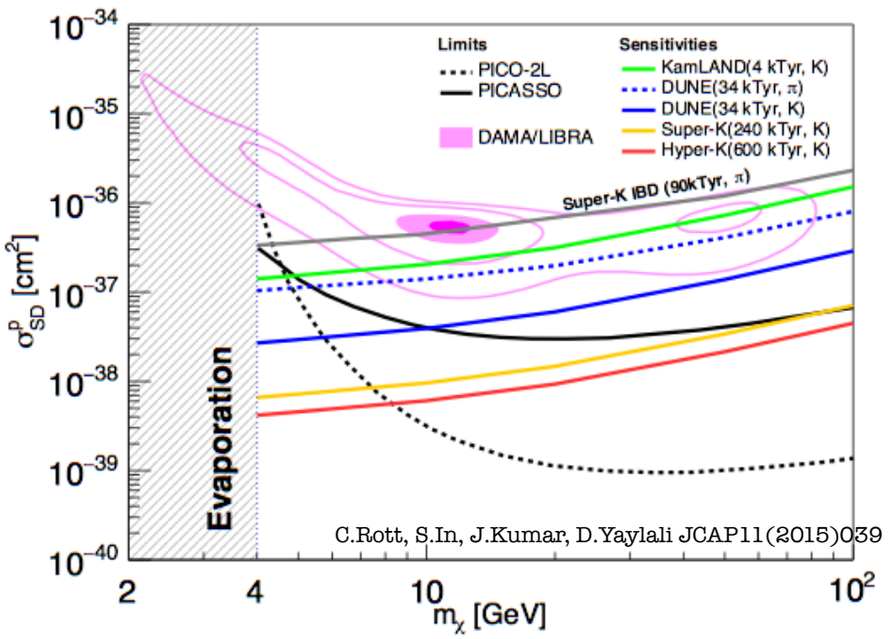
With ~10 years of data capable to distinguish the current solar and KamLAND best fit Δm^2_{21} values with 4-5σ significance

more Science …

more science…

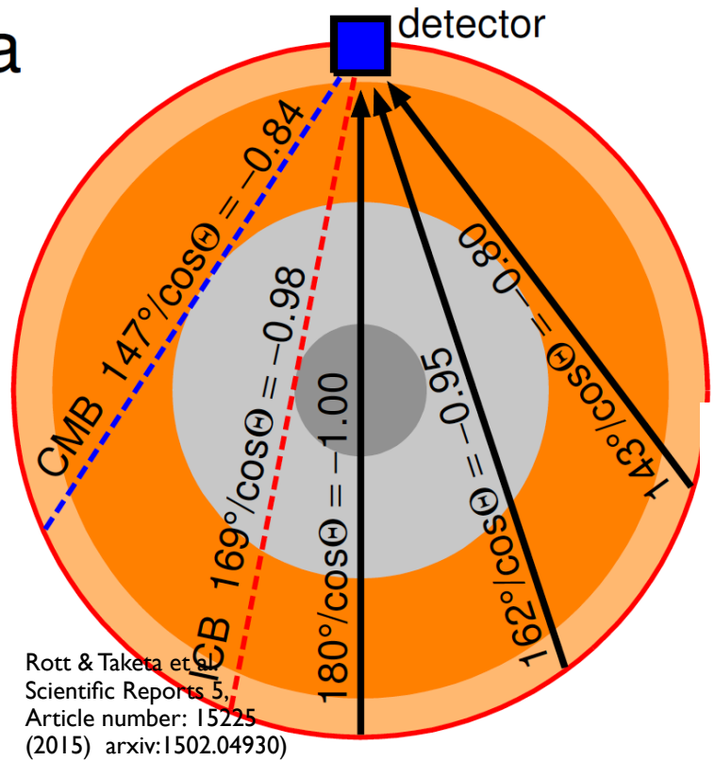
Searches for Dark Matter and Physics Beyond the Standard Model

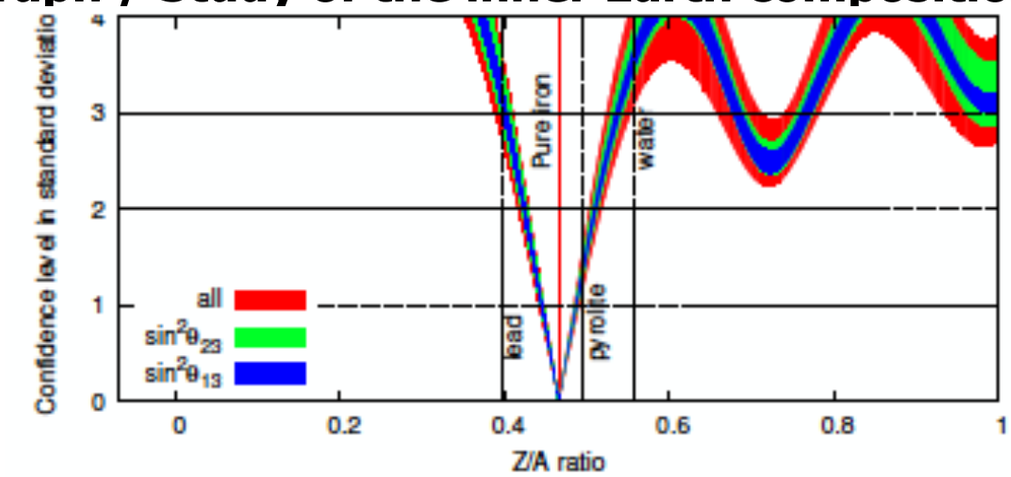


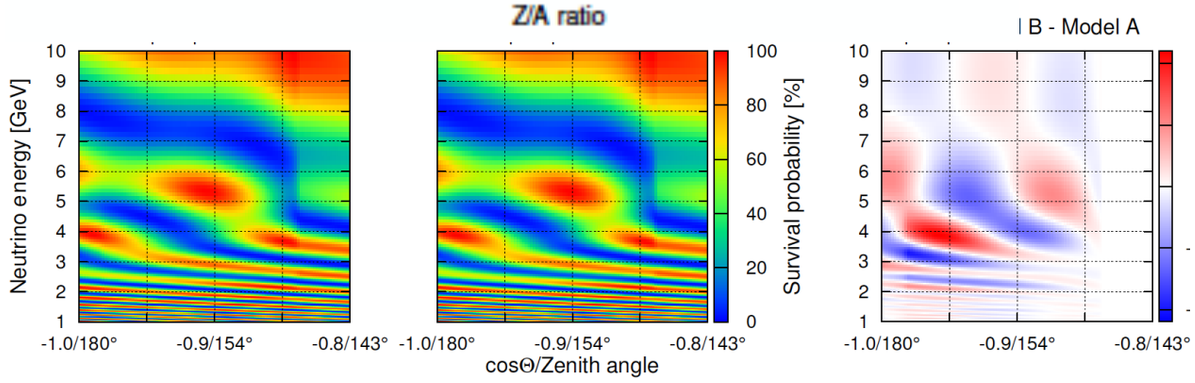


- Searches for Dark Matter captured in the Sun. Most sensitive indirect search for WIMP nucleon scattering

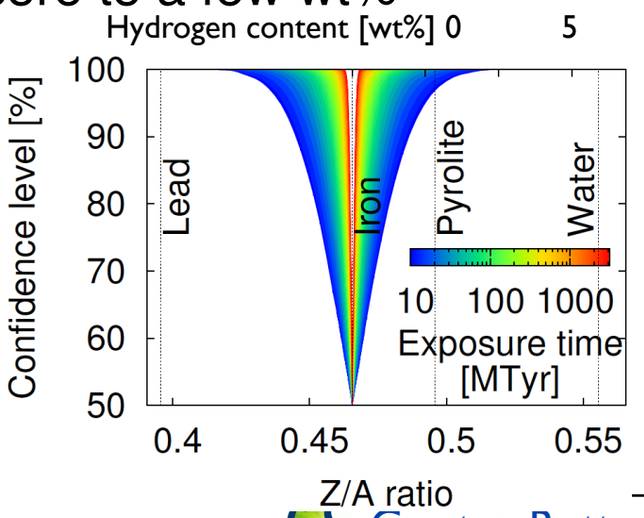
Neutrino Oscillation Tomograph / Study of the inner Earth composition







- Sensitivity to the outer Earth core composition
- Constrain the hydrogen content of the outer Earth core to a few wt%



Project Status

Hyper-K Status

- International Hyper-Kamiokande proto-collaboration has been formed
- Two host institutions: U Tokyo/ICRR and KEK/IPNS
- U Tokyo has created a new institution for Hyper-K construction: Next generation Neutrino Science Organization (NNSO)
- Hyper-Kamiokande was selected to be listed on the Large Projects Roadmap of the Japanese Ministry of Education, Culture, Sports, Science (MEXT) (August 4, 2017)
- In the end of Aug. 2018, MEXT has decided to request the budget to Ministry of Finance for "funding for feasibility study."
- Statement from the President of The University of Tokyo Concerning the Start of Hyper-Kamiokande (September 12, 2018)
  - Hyper-Kamiokande Experiment to begin construction in April 2020

Hyper-K construction to start in 2020 !
(Aiming to start operations in 2027)

Conclusions

Conclusions

- Hyper-Kamiokande will offer an extremely broad science program with the prospects of major breakthrough discoveries
  - Search for CP violation in neutrino oscillations
  - Proton decay
  - Rich program with atmospheric and solar neutrinos
  - Supernova neutrinos
- Timeline & Status
  - Hyper-Kamiokande construction to start in April 2020
  - Seed funding provided by MEXT
  - Formation of the international collaboration
  - Expect to start operations in 2027

Thanks !