Hyper-Kamiokande

The Hyper-Kamiokande project

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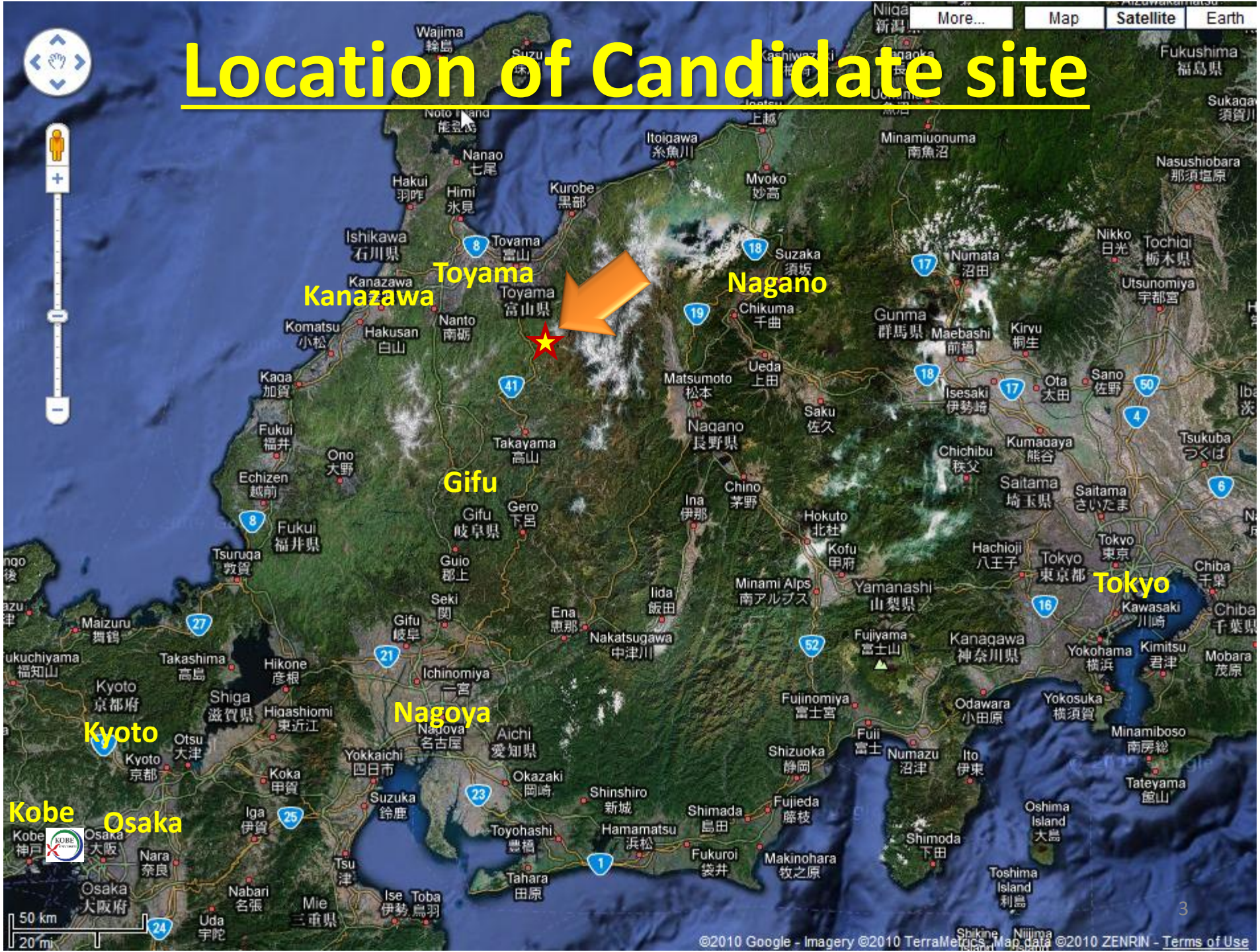
- Hyper-Kamiokande detector & current R&Ds
- Current status of the project
- Physics/Observation targets in HK
- Summary

Hyper-Kamiokande proto-collaboration

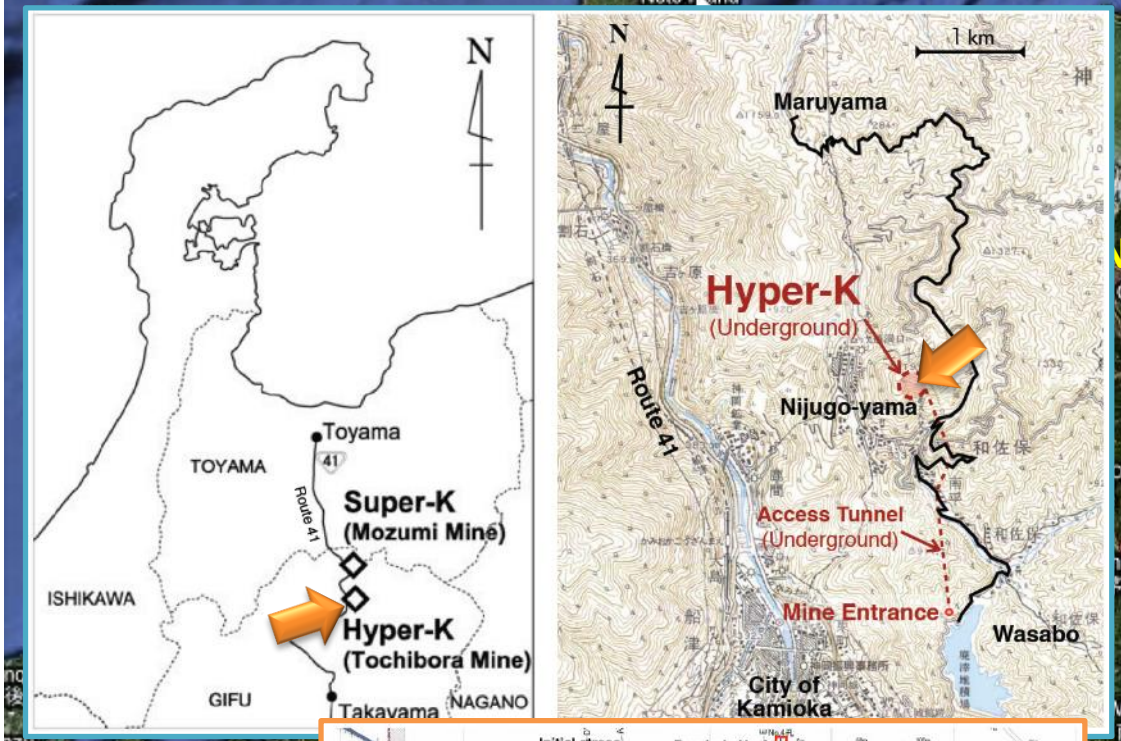
- Formed in January 2015
- ~300 members, 75 institutions, from 15 countries (as of April 2017)
- ~70% from oversea countries

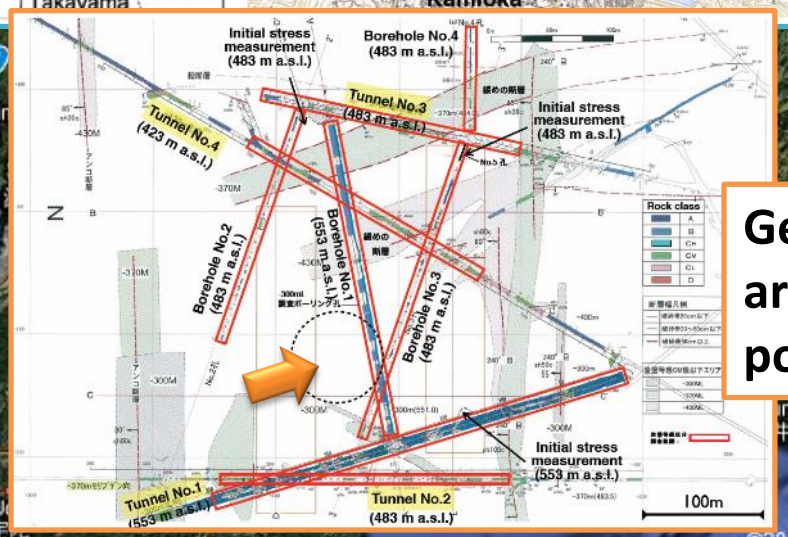
Proto-collaboration meeting at Queen Mary University of London, July 2016

Location of Candidate site



Location of Candidate site

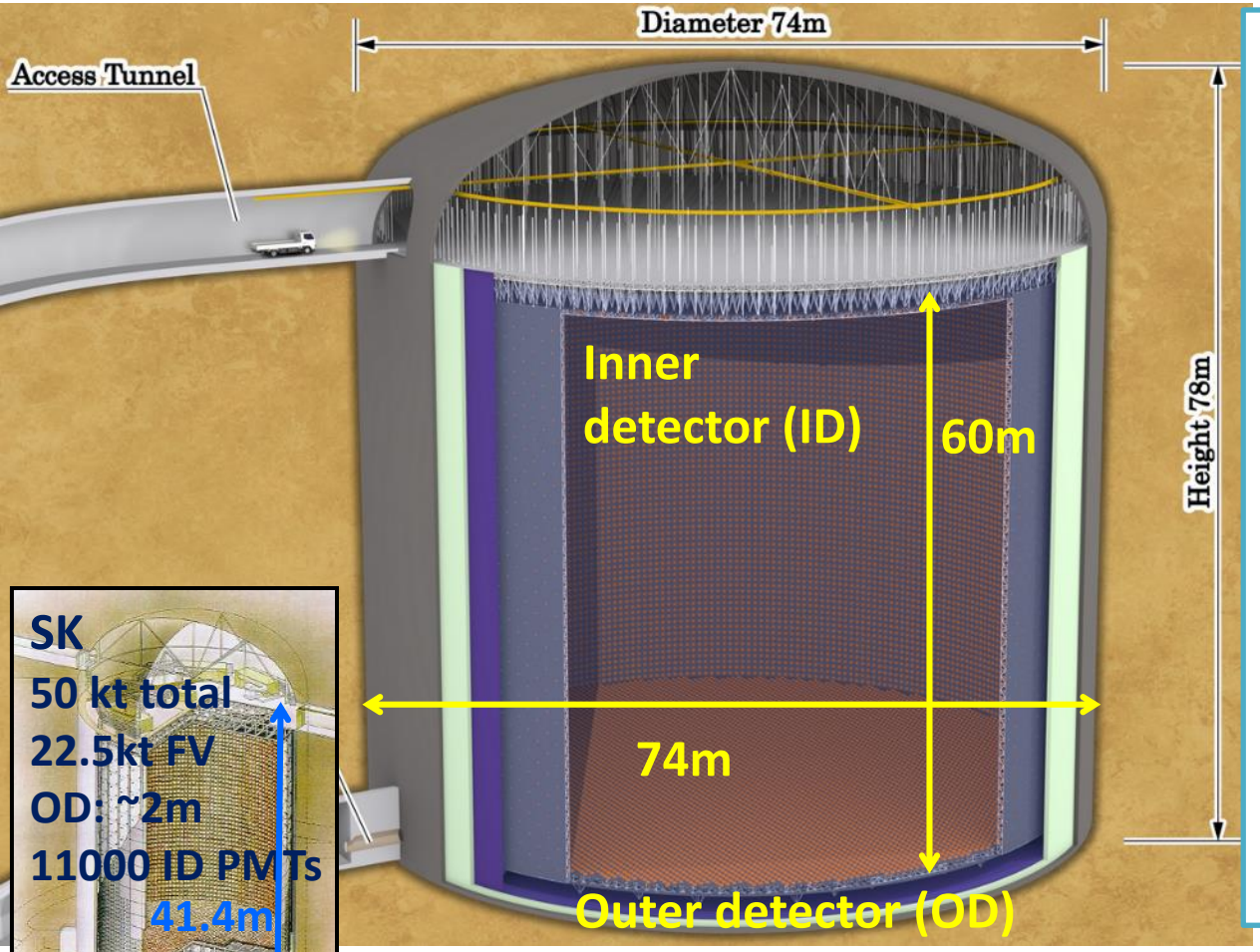




- Candidate site: Tochibora Mine, under Mt. Nijugo-yama
- ~8 km south from SK
- Overburden of Tochibora site: 650 m (1755 m.w.e.)
- Geological condition is confirmed for HK cavern construction

Geological survey around candidate position

Hyper-Kamiokande detector

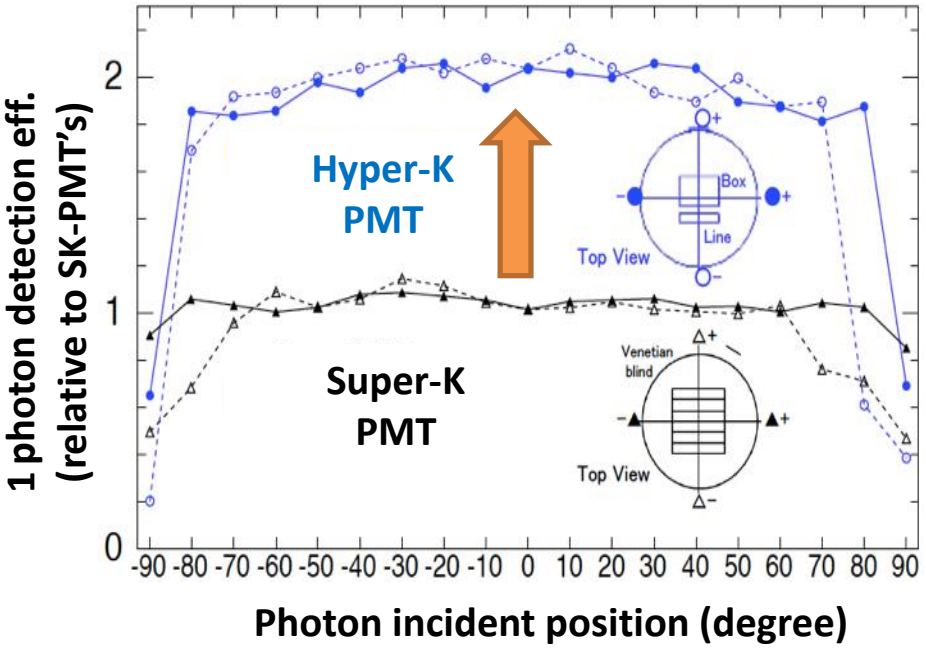


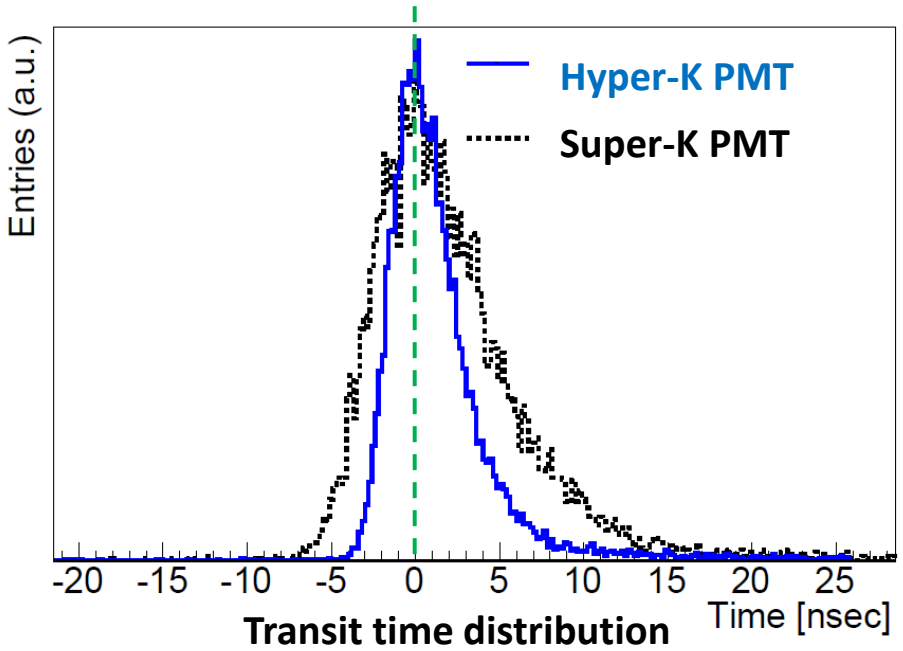
- 258 kt water
- 187 kt fid. vol. (1m from wall)
- OD: 1~2m thickness
- Photon detection efficiency:
  SK detector x 2
  - Better energy resolution
  - Better neutron tagging efficiency (~70%)
- Optional 2nd tank is under discussion.

Inner Detector (ID): ~40,000 of new 50-cm photo sensors
Outer Detector (OD): ~6,700 of new 20-cm photo sensors

New 50 cm PMT for HK

- **Current performance of new 50 cm PMT**
  - **SK-PMT x2 photon detection**
  - **SK-PMT x2 timing resolution (~1.1ns)**
  - **Higher pressure tolerance (> 80 m)**
  - **Dark rate: 7.5 kHz (as of 2016)**
    - **→ trying to reduce to SK-PMT level (< 4kHz)**

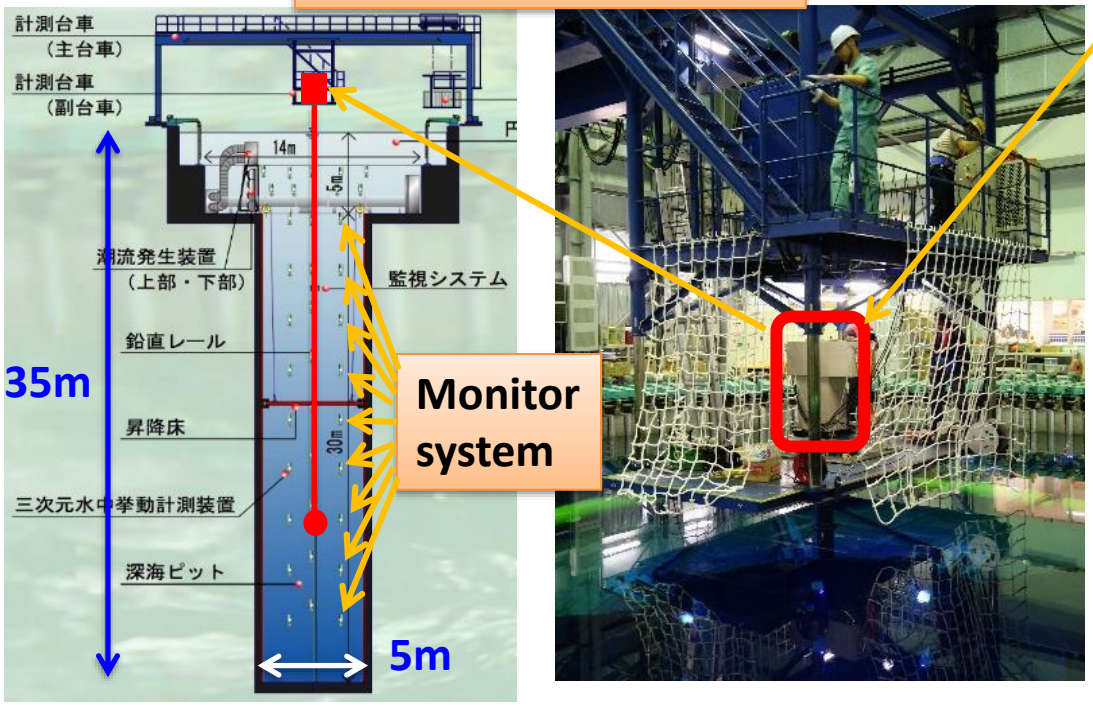


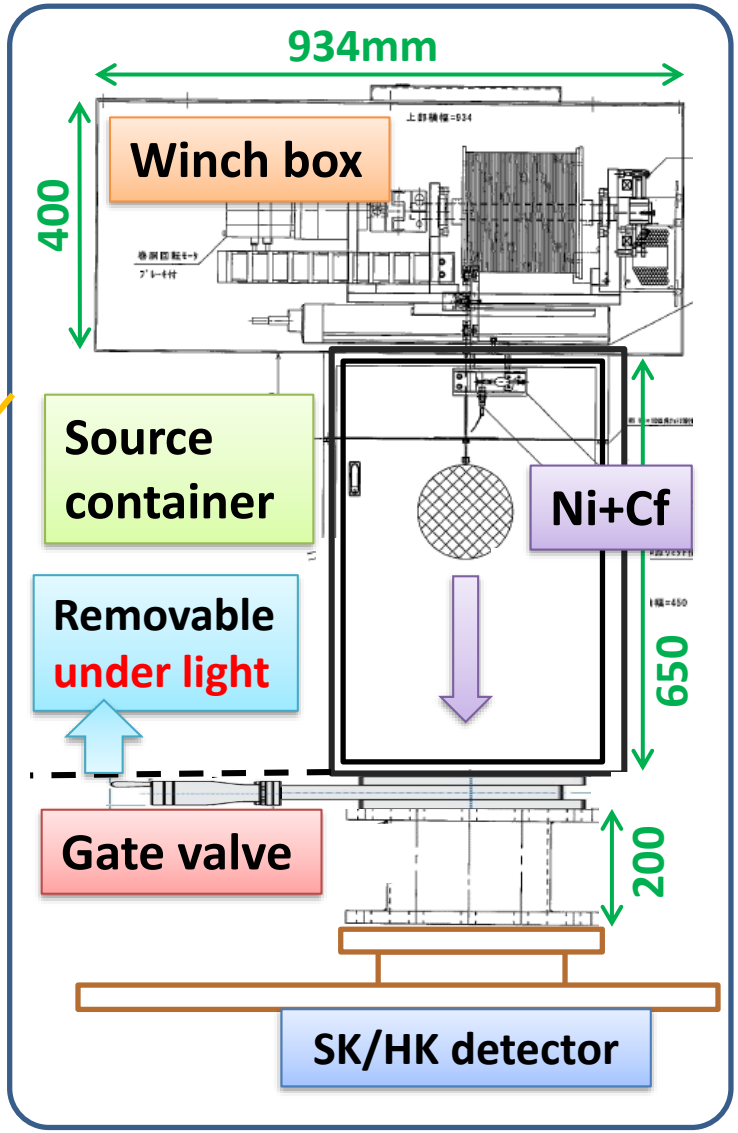


R&D of Ni-Cf deployment system

- Ni+Cf source: total ~9 MeV gamma rays
- Automated deployment by a sequencer
- Position precision: +/-5mm
- Will be used (=demonstrated) in SK
- Deep water test (~35m) was done at National Maritime Research Institute

NMRI: Deep water tank





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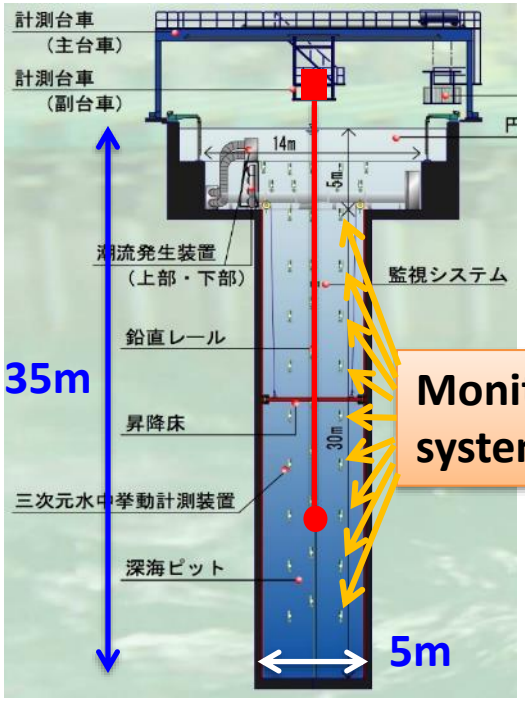
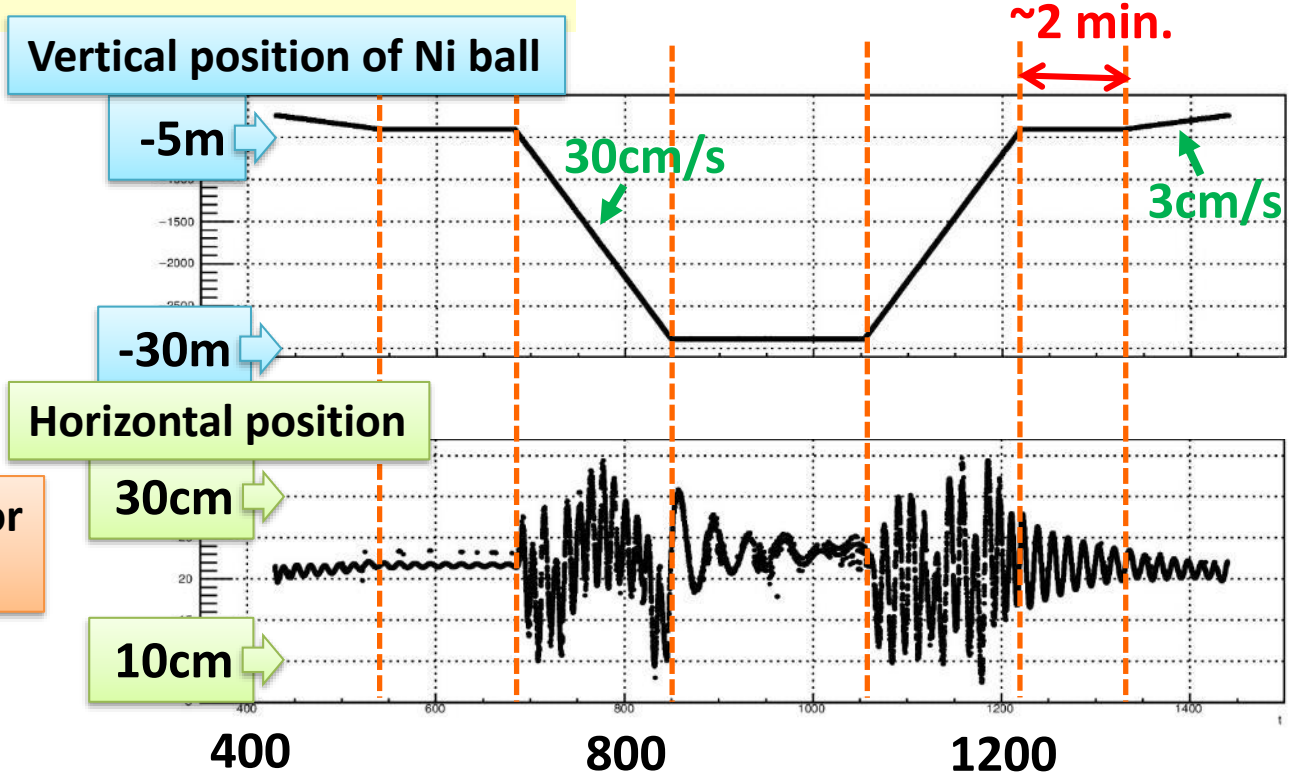
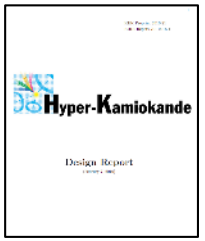
Precise movement of the Ni-Cf calibration source is obtained. → applied to safe operation



Monitor system



Current status of the project

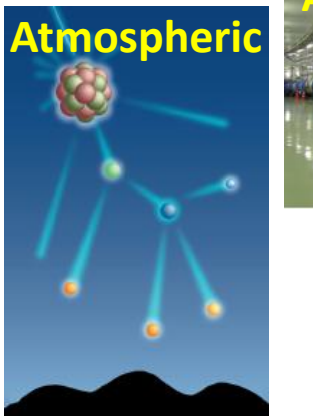


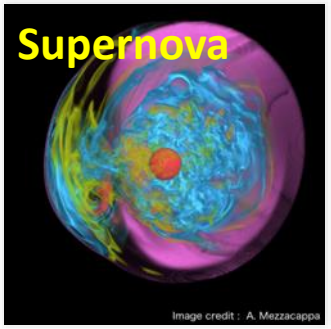
- Design Report is reviewed by Hyper-K Advisory Committee
  - KEK Preprint 2016-21, ICRR-Report-701-2016-1
- Strong commitment from host institutions (ICRR, U. Tokyo & KEK)
- Strong support from Japanese communities
  - Cosmic-ray (CRC) and high-energy (JAHEP)
- Science Council of Japan has selected HK as one of top priority large-scale research projects in "Master Plan 2017"
- MEXT is evaluating HK, and will soon release "Roadmap 2017"
  - HK is listed in the preliminary version of the Roadmap released on July 18.
- Budget request is being submitted to start construction in JFY 2018. (Aiming to start observation in 2026)

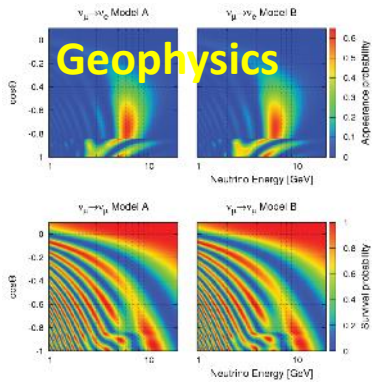
JFY 2017	2018	2019	2020	2021	2022	2023	2024	2025	2026
Geo-survey, detailed design									
	Initial facility const.								
		Access tunnel							
			Cavern excavation						
						Tank construction			
								Water filling	
				PMT/cover/electronics production					
									Operation

Physics/Observation targets in HK

- Accelerator based neutrinos
- Atmospheric neutrinos
- Solar neutrinos
- Supernova neutrinos
- Other astrophysical neutrinos
  - WIMP searches, solar flare, GRB, …
- Nucleon decay
- Neutrino geophysics



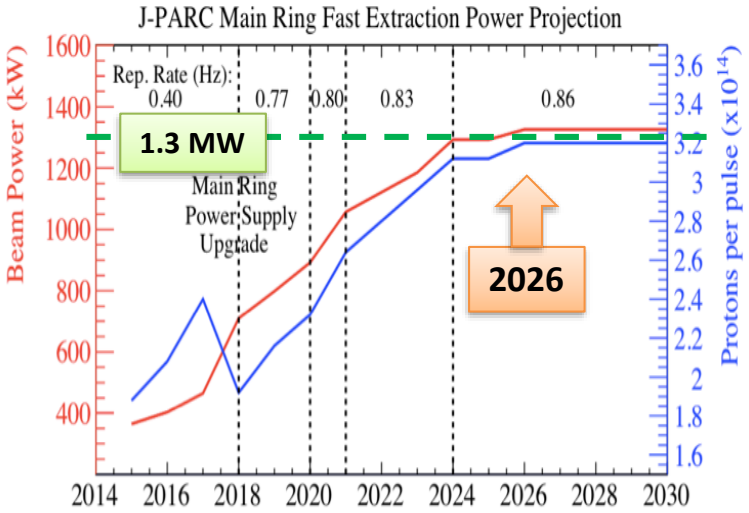


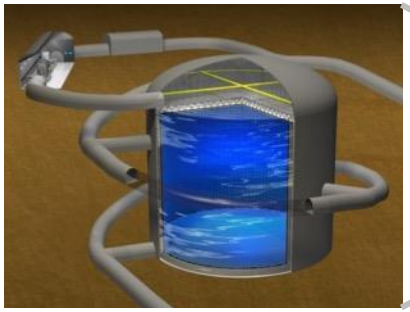


Accelerator based neutrinos

- Common base line, same off-axis (2.5 degree) narrow band, high beam power (1.3 MW)
  - In 2016, KEK Project Implementation Plan put first priority to "J-PARC upgrade for Hyper-K"
- Huge statistics with high S/N
  - ~3000 appearance signals [/10yr]

J-PARC MR fast extraction power projection





Hyper-K

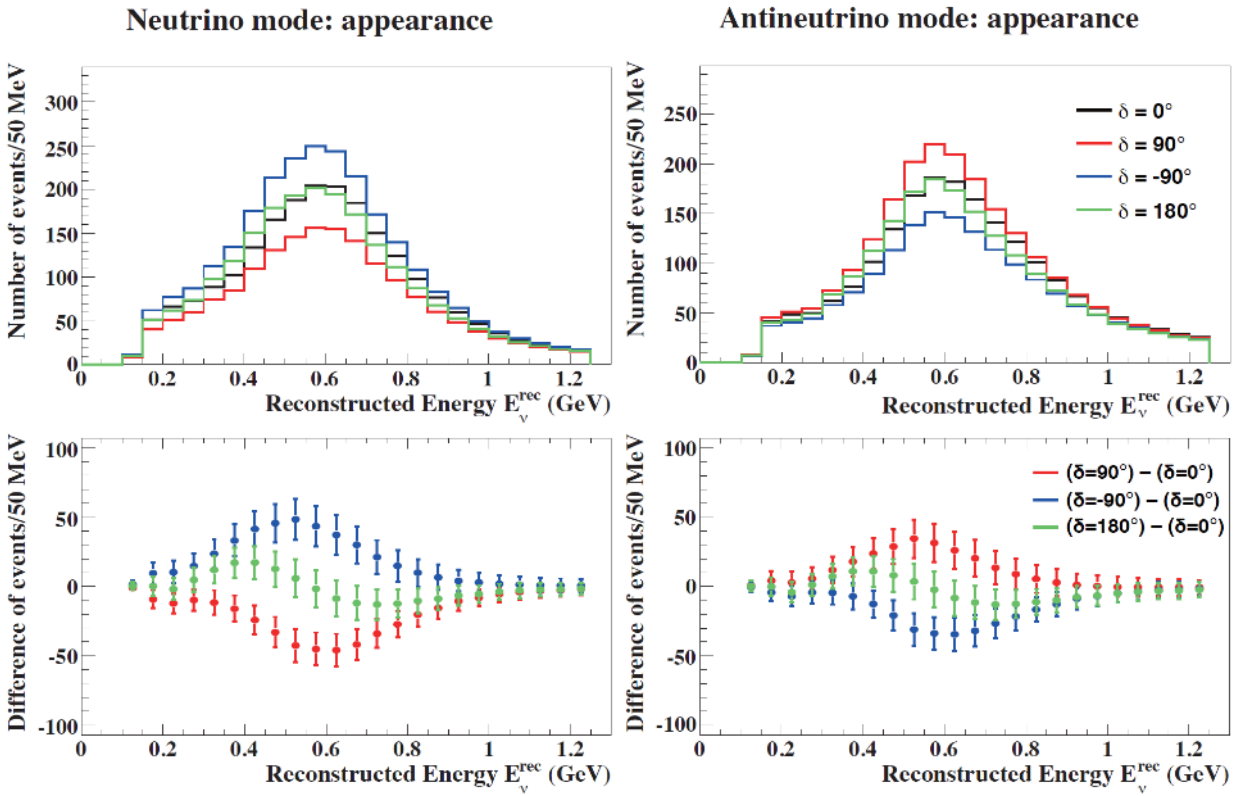
J-PARC

Accelerator Complex

Expected events in Hyper-K CPV Study

Number of signal candidate events, 1.3 MW × 10 years (10^8 sec), $\nu:\bar{\nu} = 1:3$

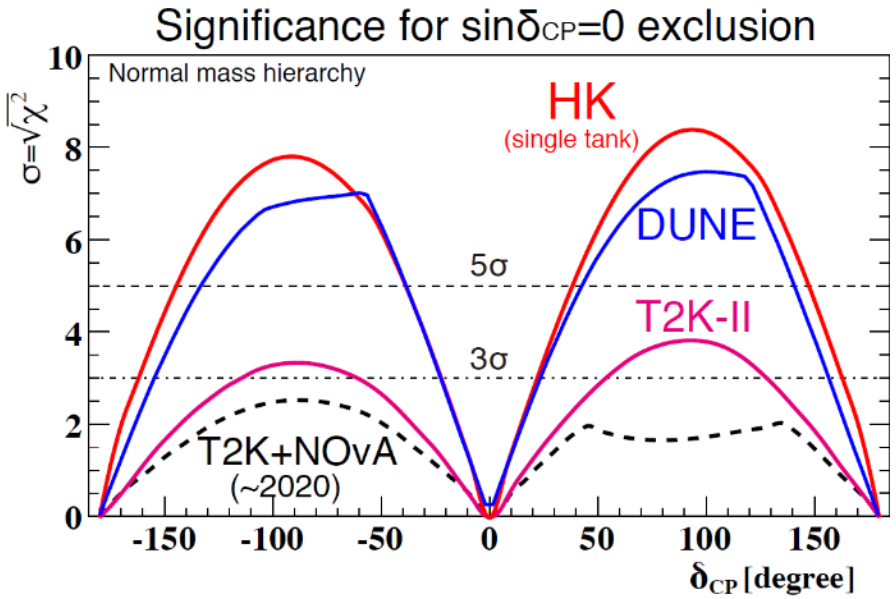
for $\delta_{CP} = 0$	Signal $\nu_\mu \rightarrow \nu_e$ CC	Wrong sign appearance	background: $\nu_\mu+\bar{\nu}_\mu$ CC	background: Beam $\nu_e+\bar{\nu}_e$ contamination	background: NC
ν beam	1,643	15	7	259	134
$\bar{\nu}$ beam	1,183	206	4	317	196

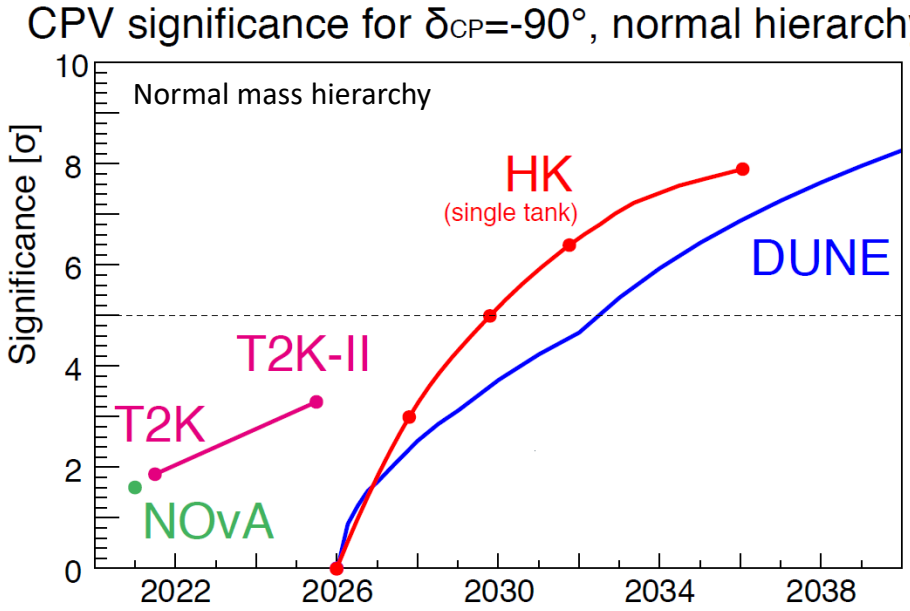


Large difference around δ_{CP} = +/-90 degree

$\sin^2 2\theta_{13}$=0.1
Normal mass hierarchy

Expected sensitivity on CPV





1.3 MW × 10 years (10^8 sec), ν:$\bar{\nu}$ = 1:3

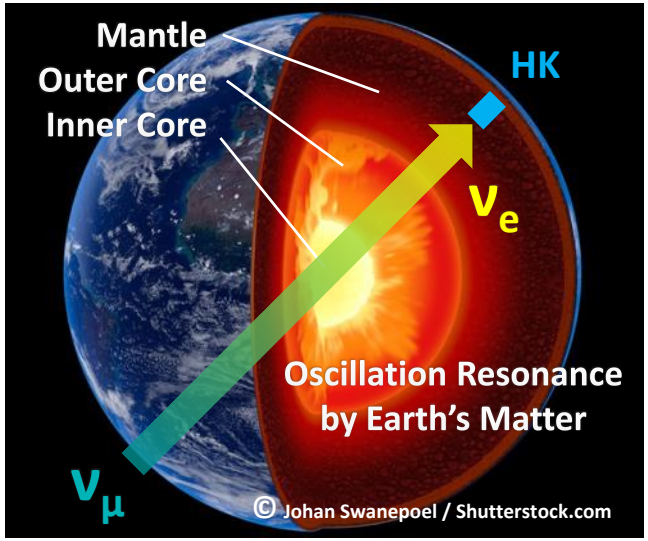
- **~8σ exclusion if δ_{CP} = +/-90°**
  ~6σ exclusion if δ_{CP} = +/-45°
- **Observe CPV for 60% of δ_{CP} with >5σ significance**

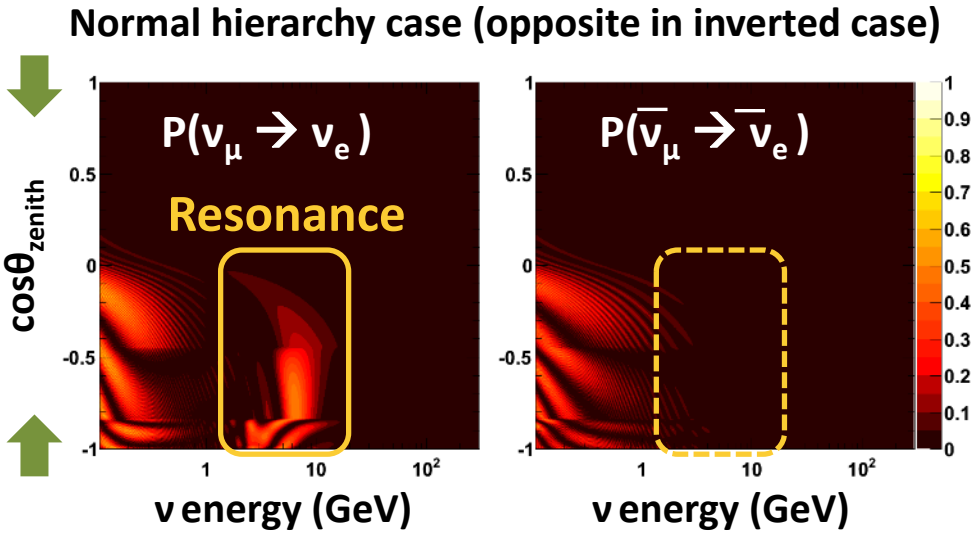
Assuming start in 2026

- **T2K favors δ_{CP} = -90°**
  - **PRL 118, 151801 (2017)**
  - **Super-K atmospheric ν data also**
- **It could be possible that ongoing experiments discover CPV (~3σ)**
- **T2K → T2K-II → Hyper-K**
- **Seamless program to get timely results**

Mass hierarchy determination in HK

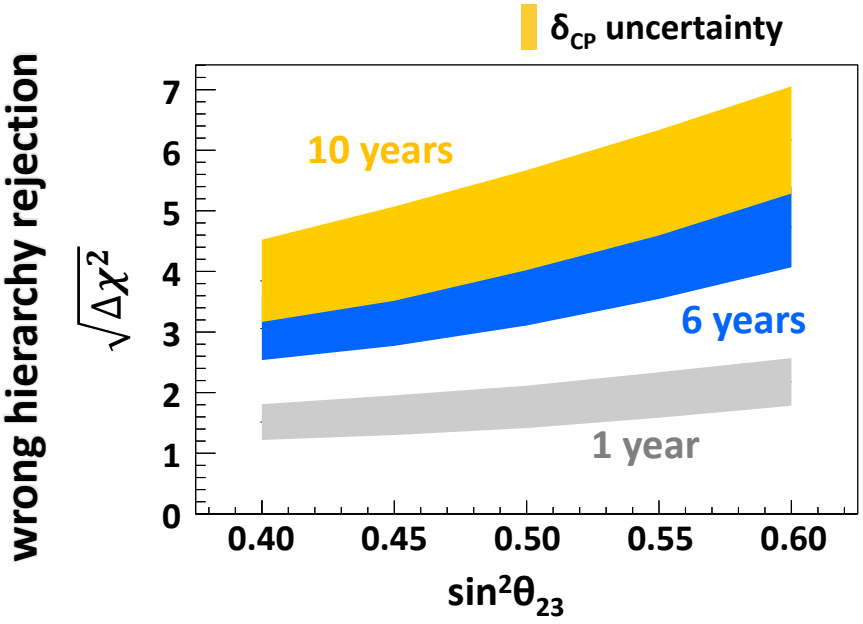
- Difference of matter effect in Earth could be seen in upward-going multi-GeV ν_e sample in atmospheric neutrinos
- Combine Atmospheric ν + Beam ν data to study mass hierarchy
  - Precise oscillation parameters: from beam ν
  - Mass ordering effect: from atmospheric ν



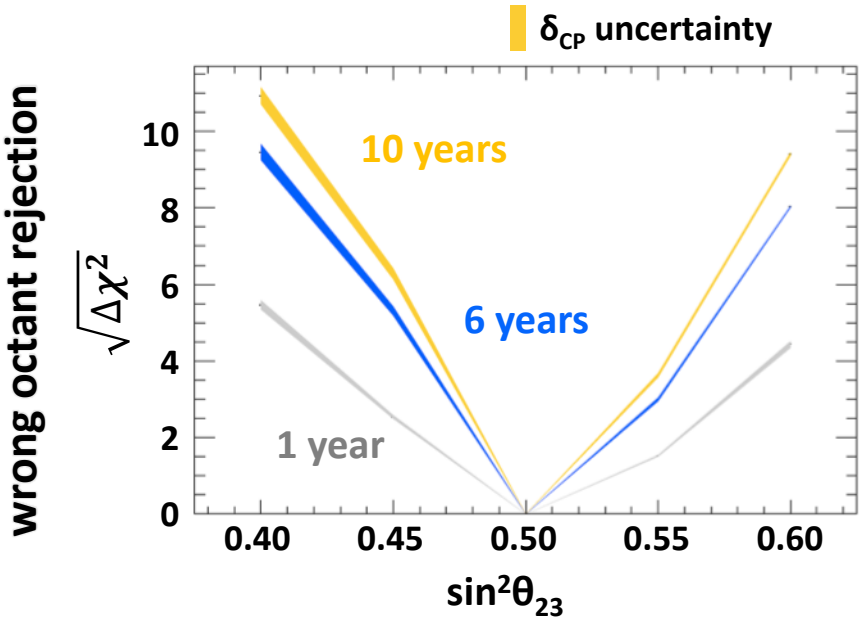


Mass hierarchy sensitivity in HK

Neutrino Mass Hierarchy



θ_{23} Octant



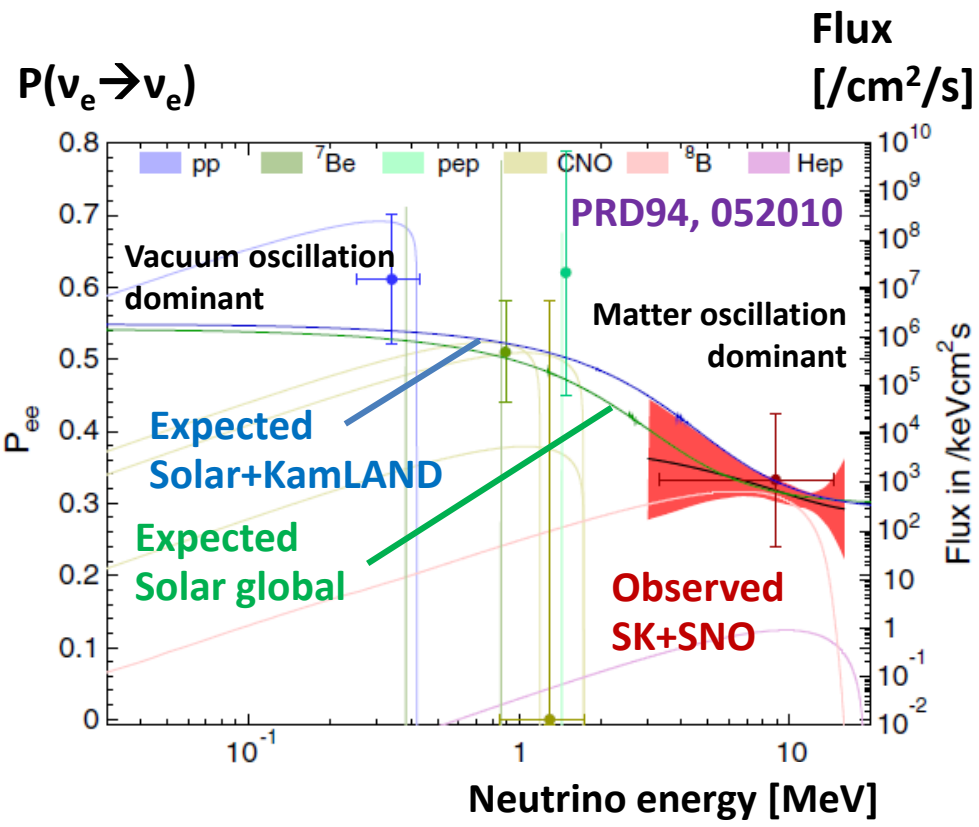
- **Mass hierarchy /θ_{23} octant determination within several years for the nearly entire parameter space**

Solar neutrinos

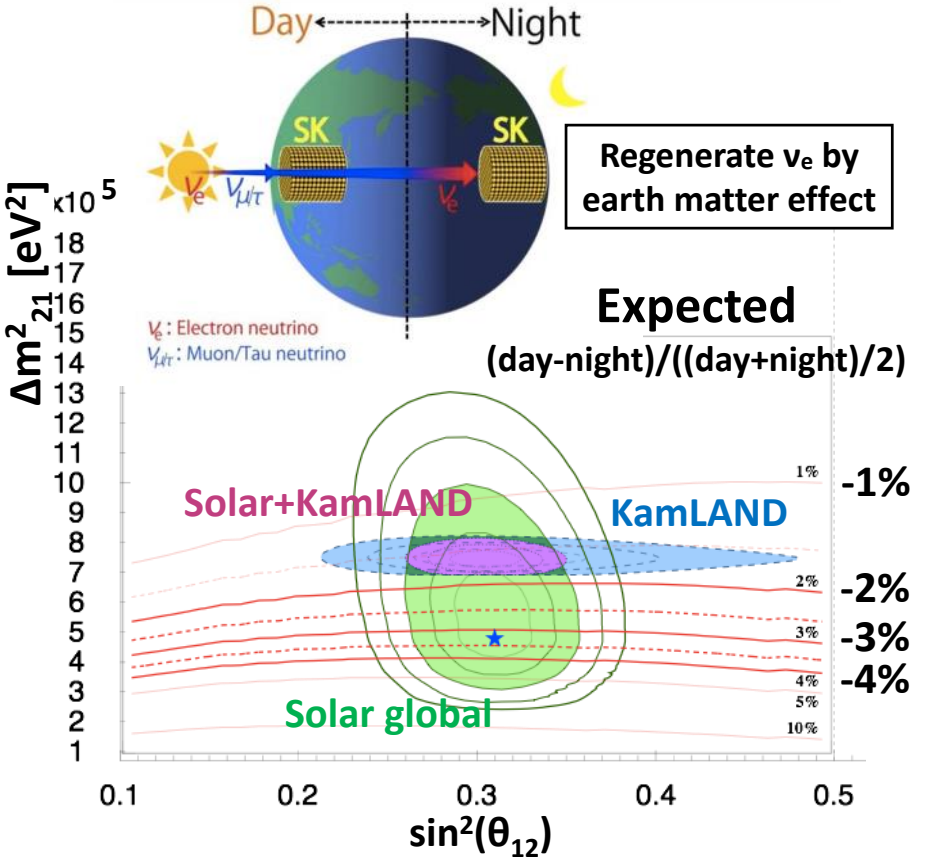
- High statistics measurement of ^{8}B solar neutrinos
  - Possible time variation of the flux
  - **Energy spectrum distortion** due to solar matter effect
  - **Day-night flux asymmetry** due to earth matter effect

$$A_{DN} = \frac{(Day - Night)}{(Day + Night)/2}$$

Spectrum distortion

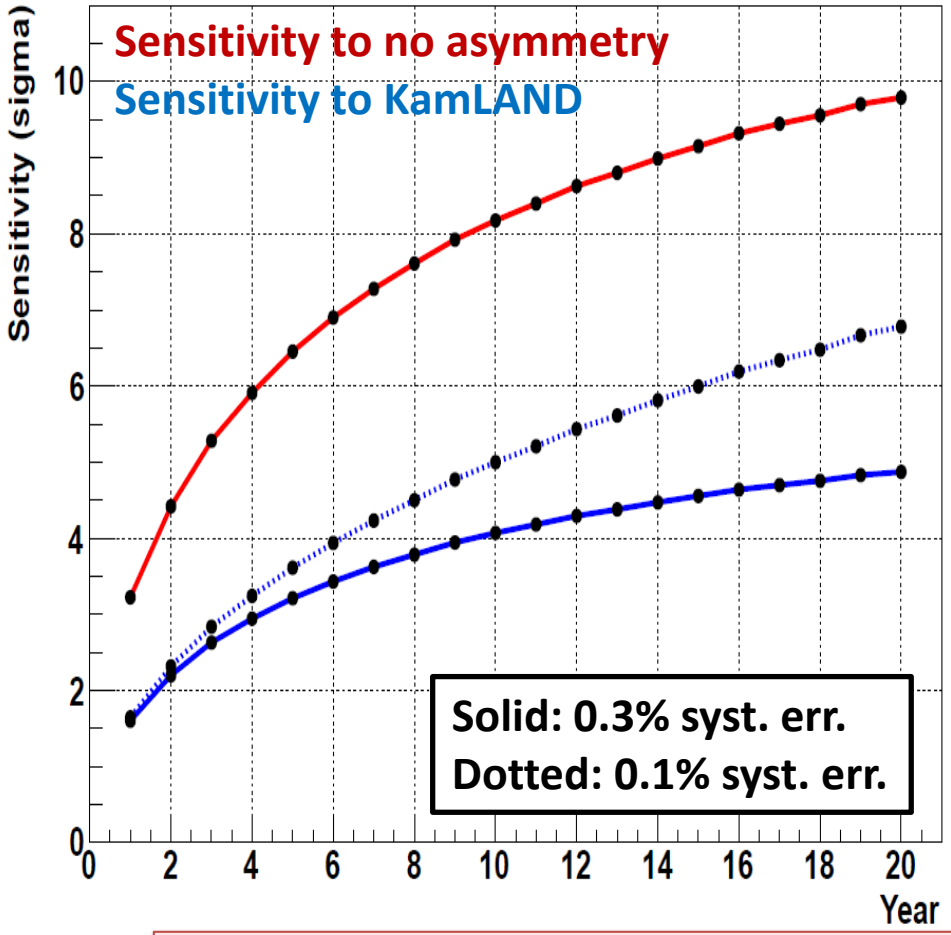


Day-Night flux asymmetry

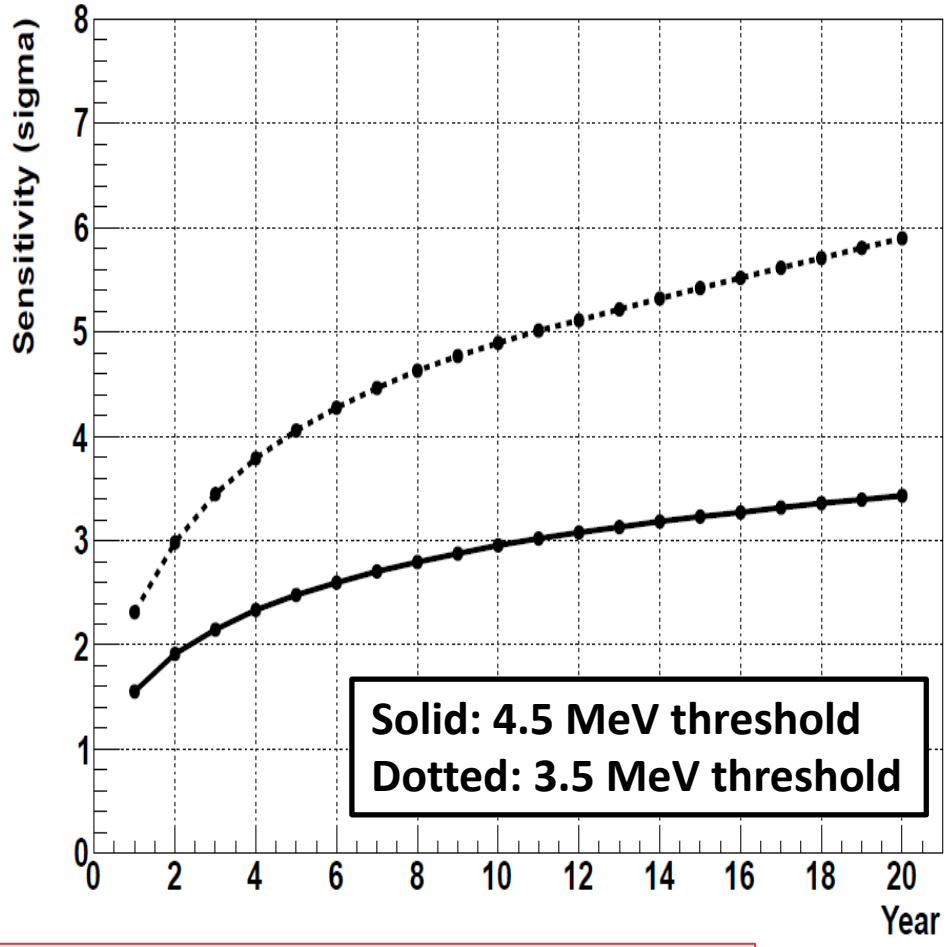


Solar neutrino measurements in HK

Day/Night sensitivity



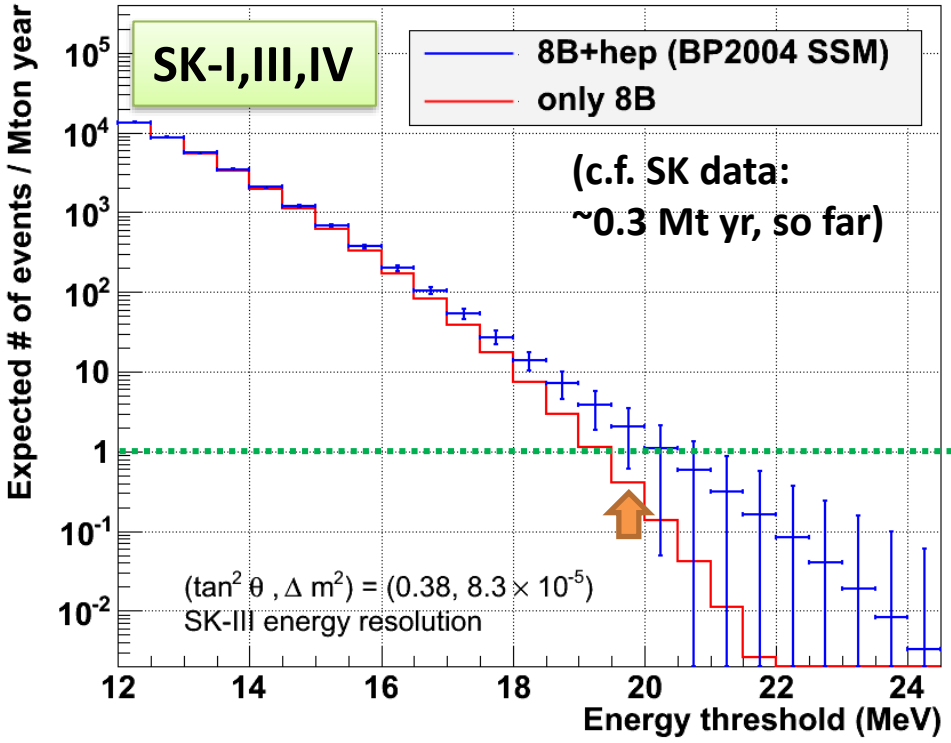
Spectrum upturn

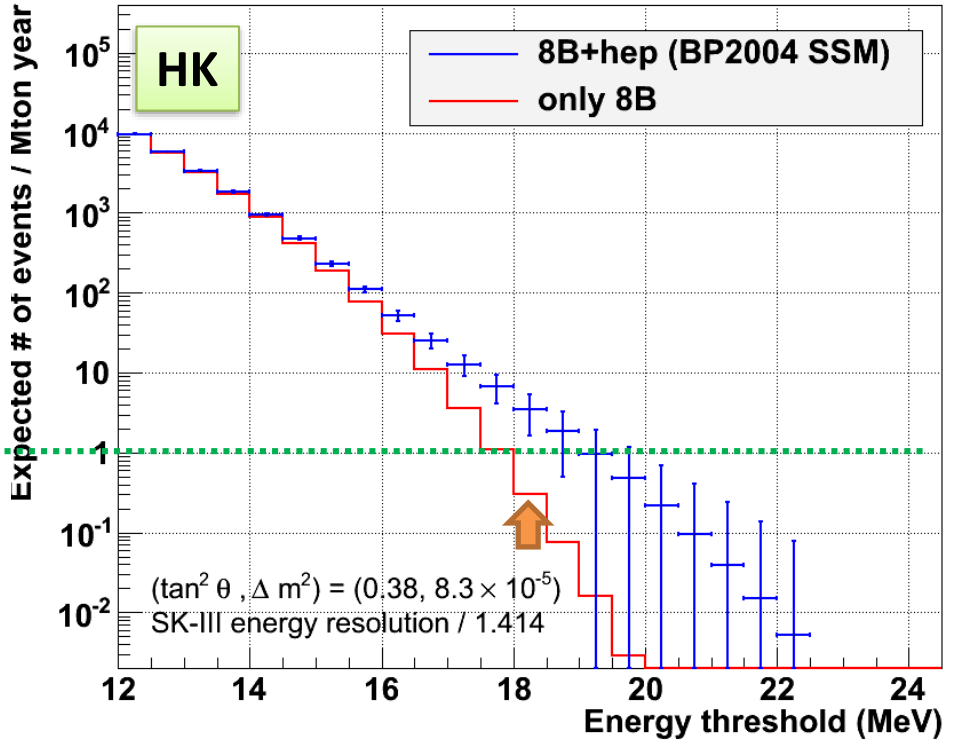


- Day/Night (solar vs reactor): 4~5 sigma in 10 years
- Spectrum upturn: ~3 sigma in 10 years

Solar hep neutrino

Integrated # of expected solar neutrino events



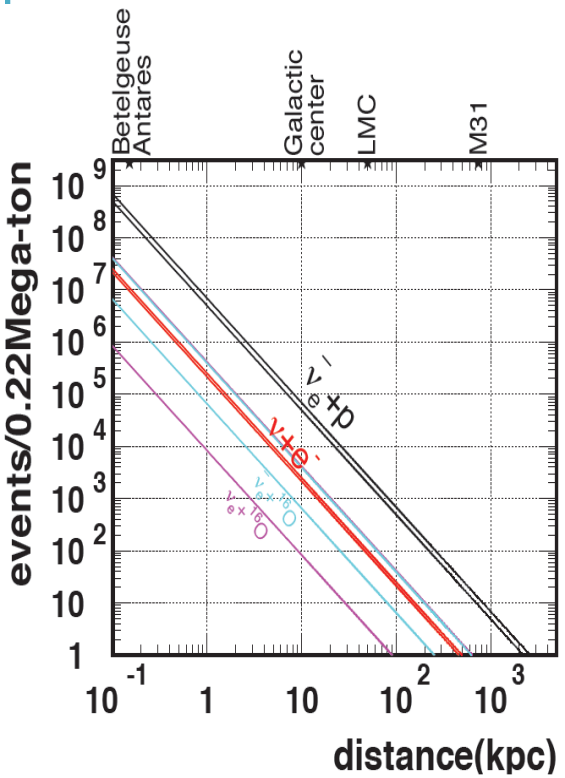


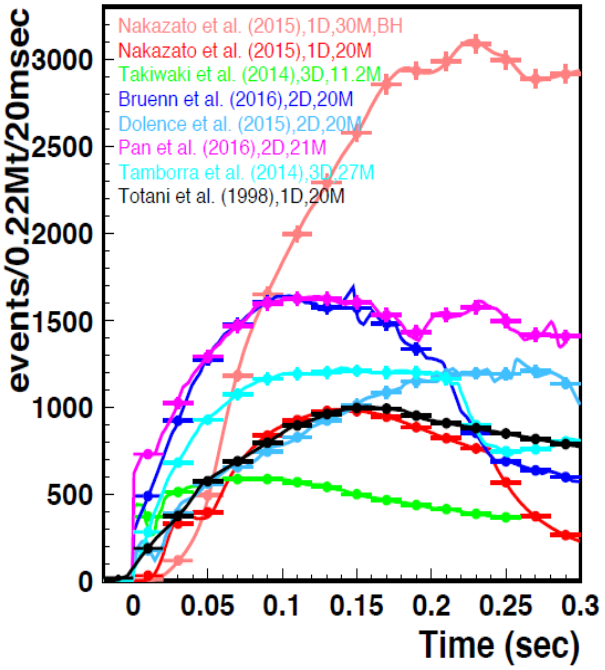
	E_{total} [MeV]	^{8}B [/Mt yr]	Hep [/Mt yr]	Hep / ^{8}B
SK-I,III,IV	19.5-25.0	0.41	1.62	3.9
HK	18.0-25.0	0.30	3.23	10.6

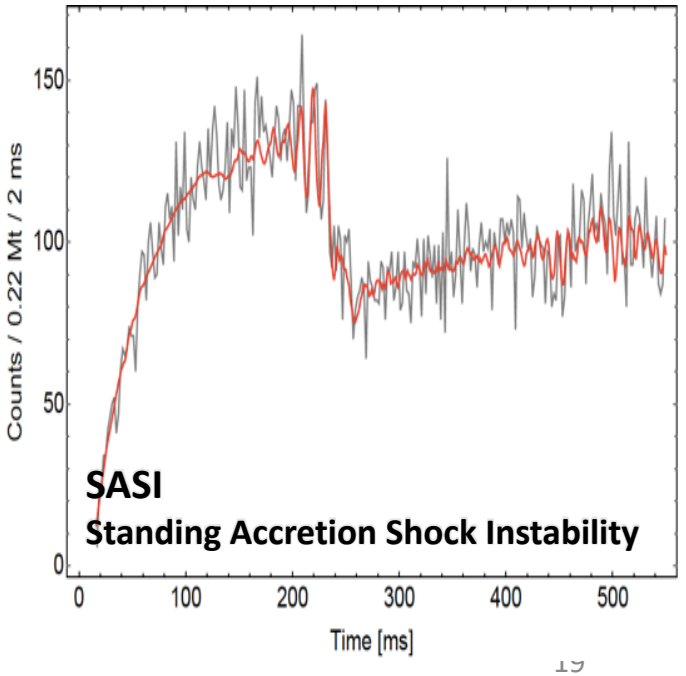
- First direct observation.
- Energy resolution (= high photon detection) is essential.

Supernova burst neutrinos

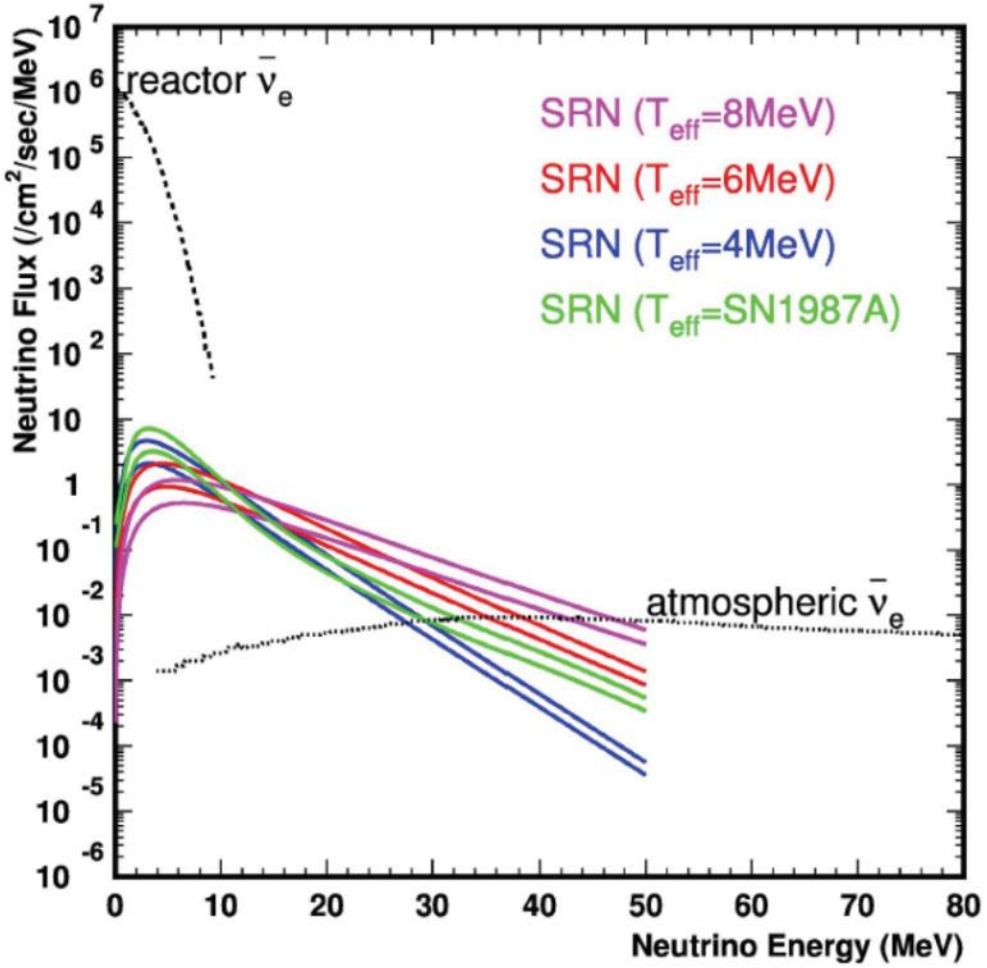
- 52-79 k events / SN at 10 kpc (in 0.22 Mt FV)
  - ~10 events / SN in Andromeda
- Precise time profile, energy profile
  - 3% level SASI could be detected from 90% of SN in our Galaxy
- Multi messenger performance:
  - ~1 degree (opening angle) determination of direction of SN at 10 kpc







Supernova relic neutrinos

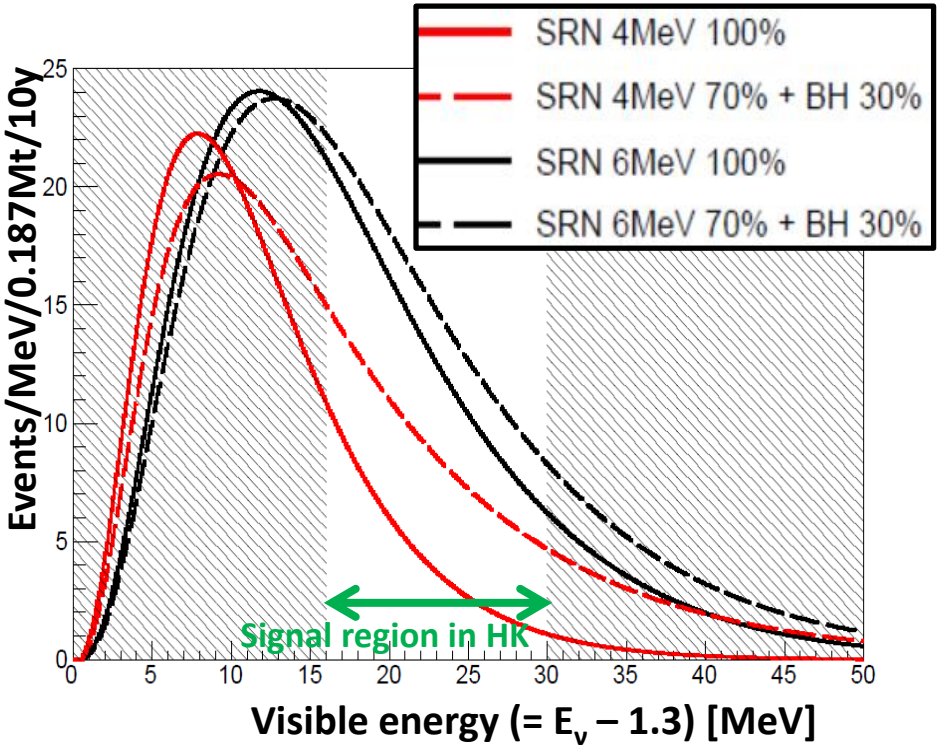


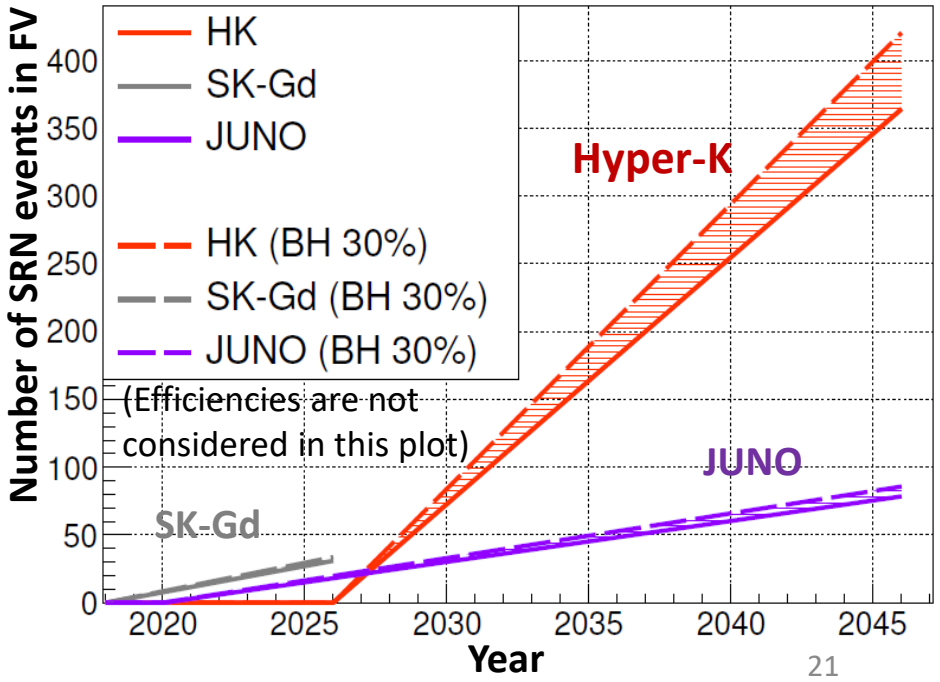
- Supernova relic neutrino (SRN) or Diffuse supernova neutrino background (DSNB)
- Accumulation of past SN bursts
- Spectrum depends on the time when SN burst
- Early time → larger red shift → low temperature
- SK-Gd is expected to discover SRN

Supernova relic neutrinos

Goal of HK: measure energy spectrum of SRN

- Study history of star formation / black hole formation
- Expected 70+/-17 events in HK 10 years (4 σ to non-zero)
  - 5 years (15 years) → 3 σ (5 σ)

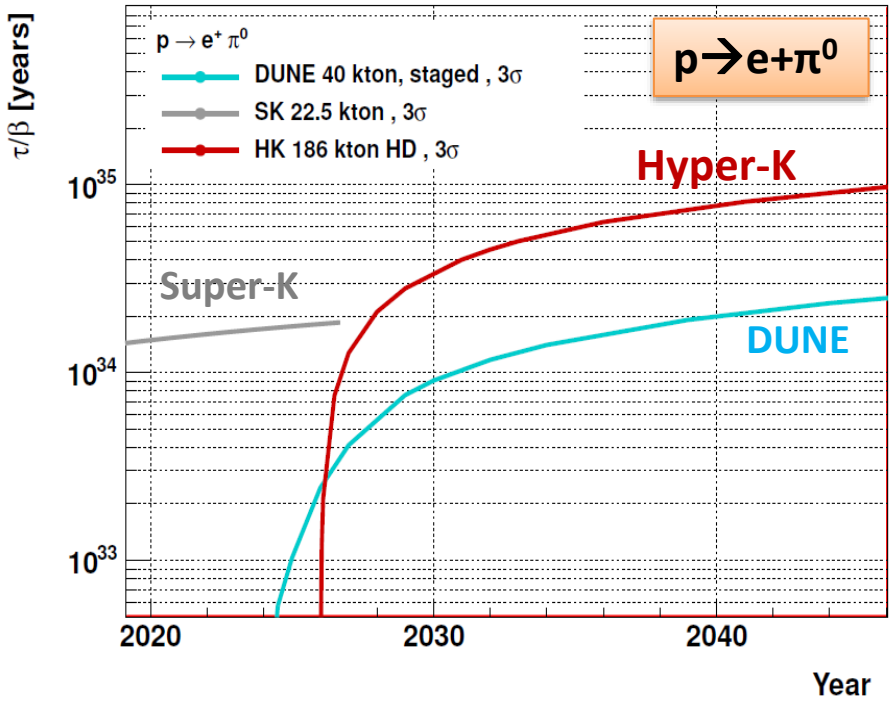


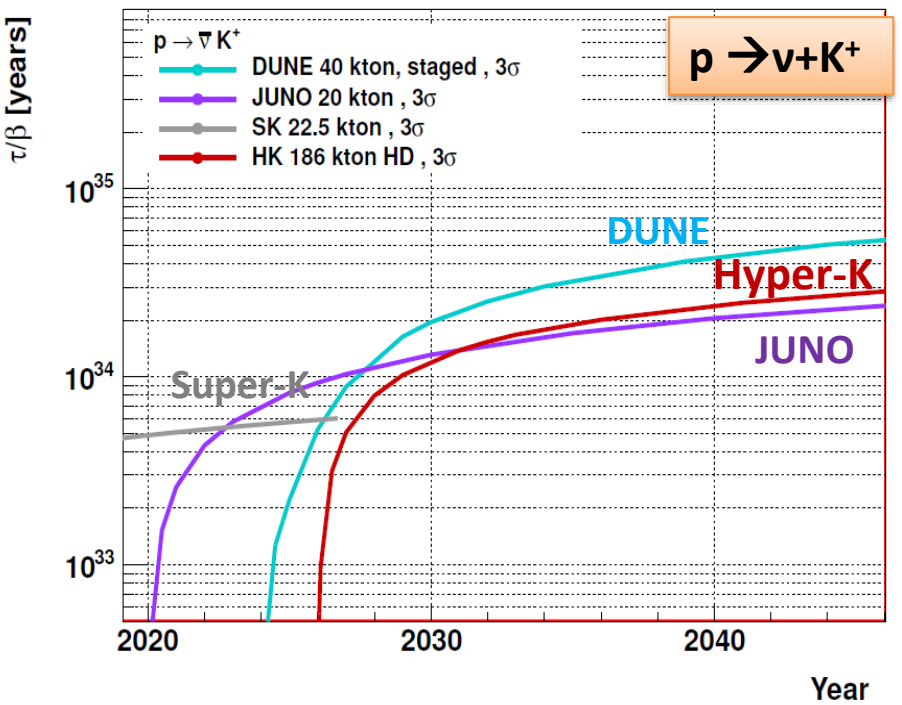


Nucleon decays

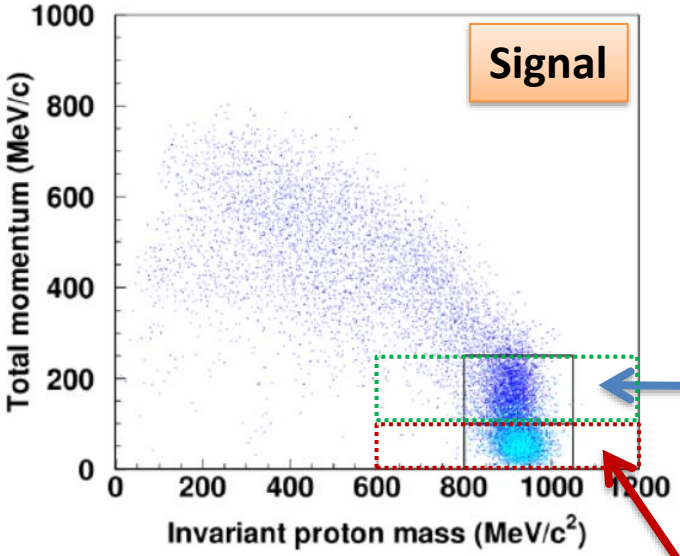
- For $e+\pi^0$ mode, atmospheric ν background could be reduced by better neutron tagging
  - 0.06 BG event/Mton·year
- For $\nu+K^+$ mode, K^+ identification efficiency improved by new PMTs

3σ discovery sensitivity

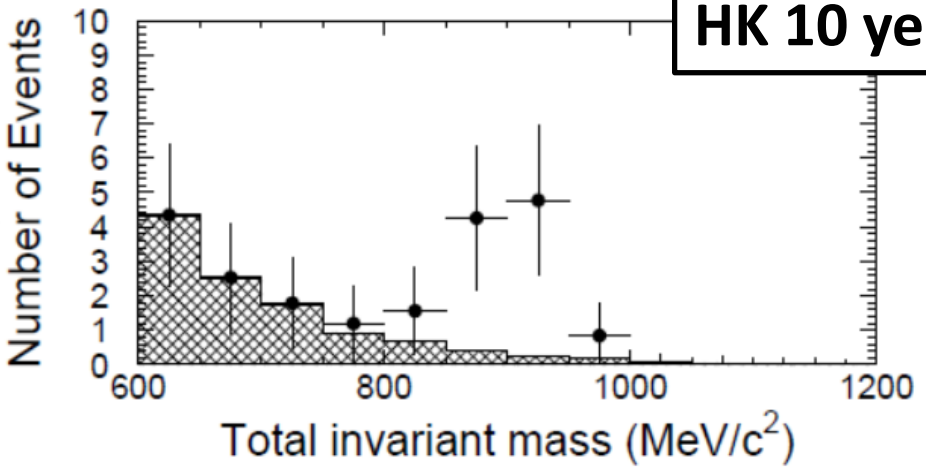


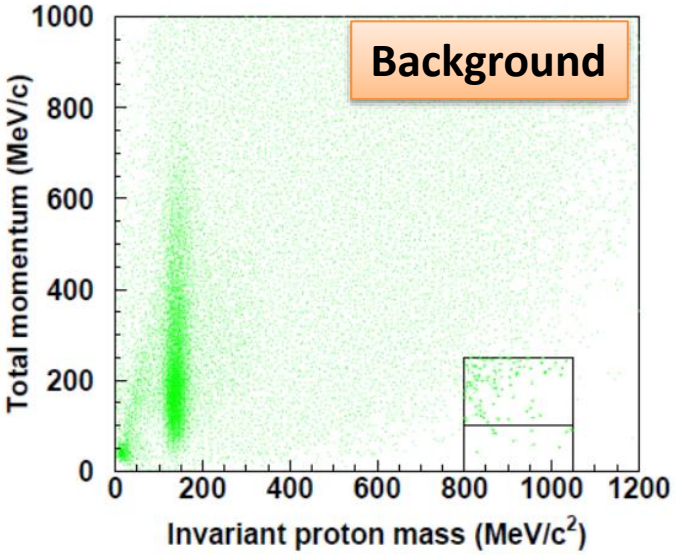


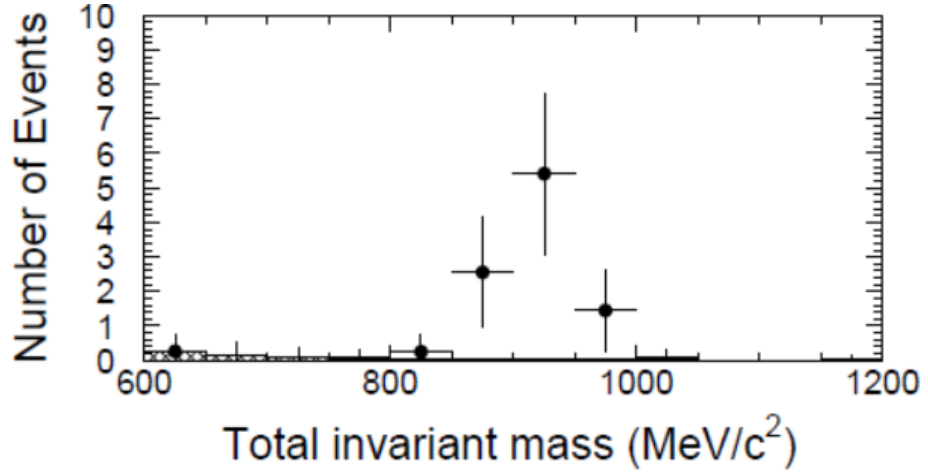
Expected distributions of $p \rightarrow e^+\pi^0$



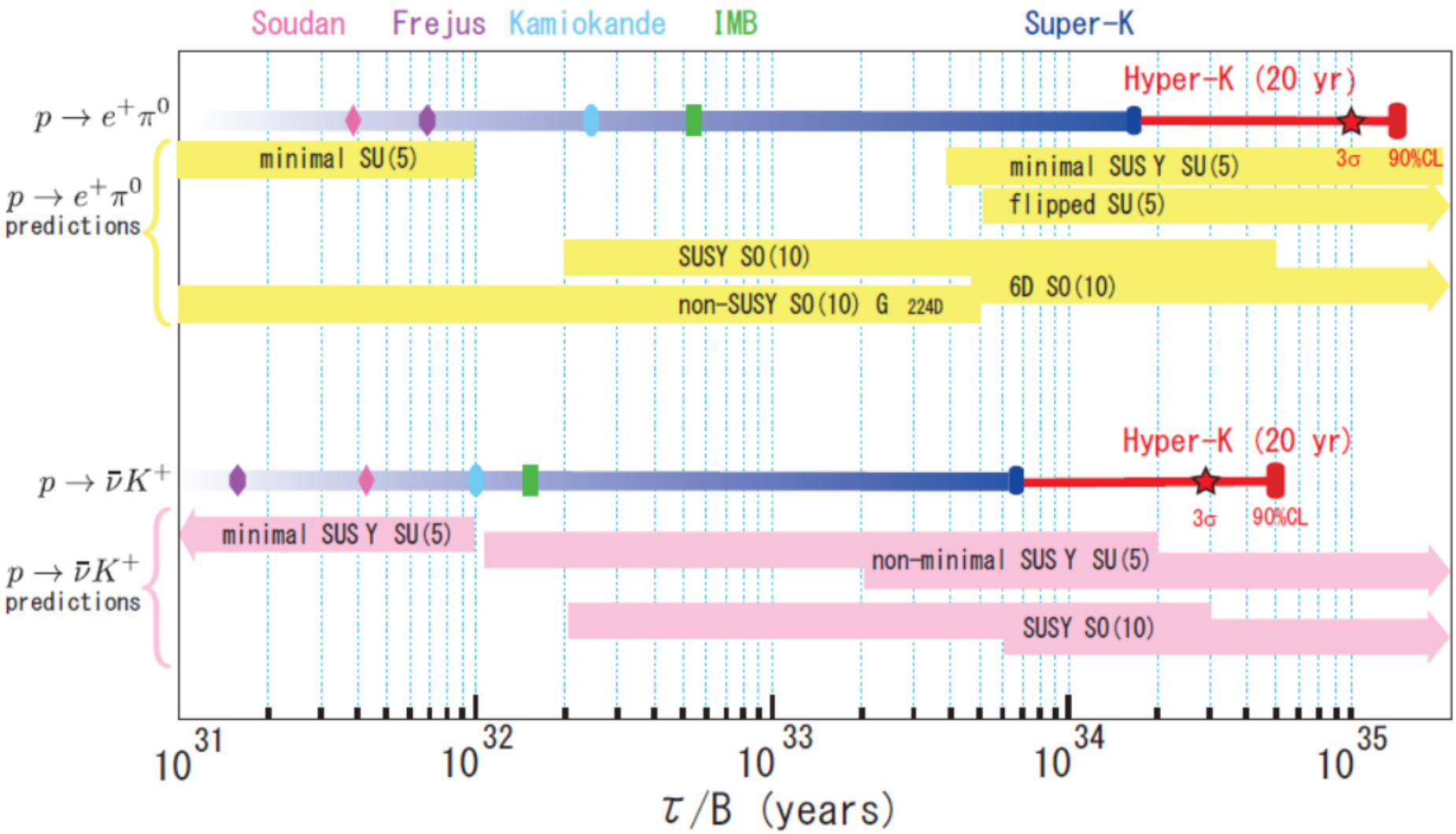
$p \rightarrow e^+\pi^0$, assuming $\tau=1.6\times10^{34}$ year







Predictions & experiments of proton decay



Summary

- **Hyper-Kamiokande will have a rich program with world-leading science output.**
  - **Leptonic CP violation, Mass hierarchy, precise neutrino oscillation study, supernova neutrinos, indirect WIMP searches, nucleon decays, neutrino geophysics, …**
- **Project being accelerated towards an early approval.**
  - **Strong supports from Japanese communities and host institutions**
  - **Good evaluation from Science Council of Japan**
  - **Listed in the preliminary version of the Roadmap by MEXT**
  - **Budget request is being issued in Japan to start construction in JFY 2018**
- **Open for new participations.**