

Hyper-Kamiokande experiment

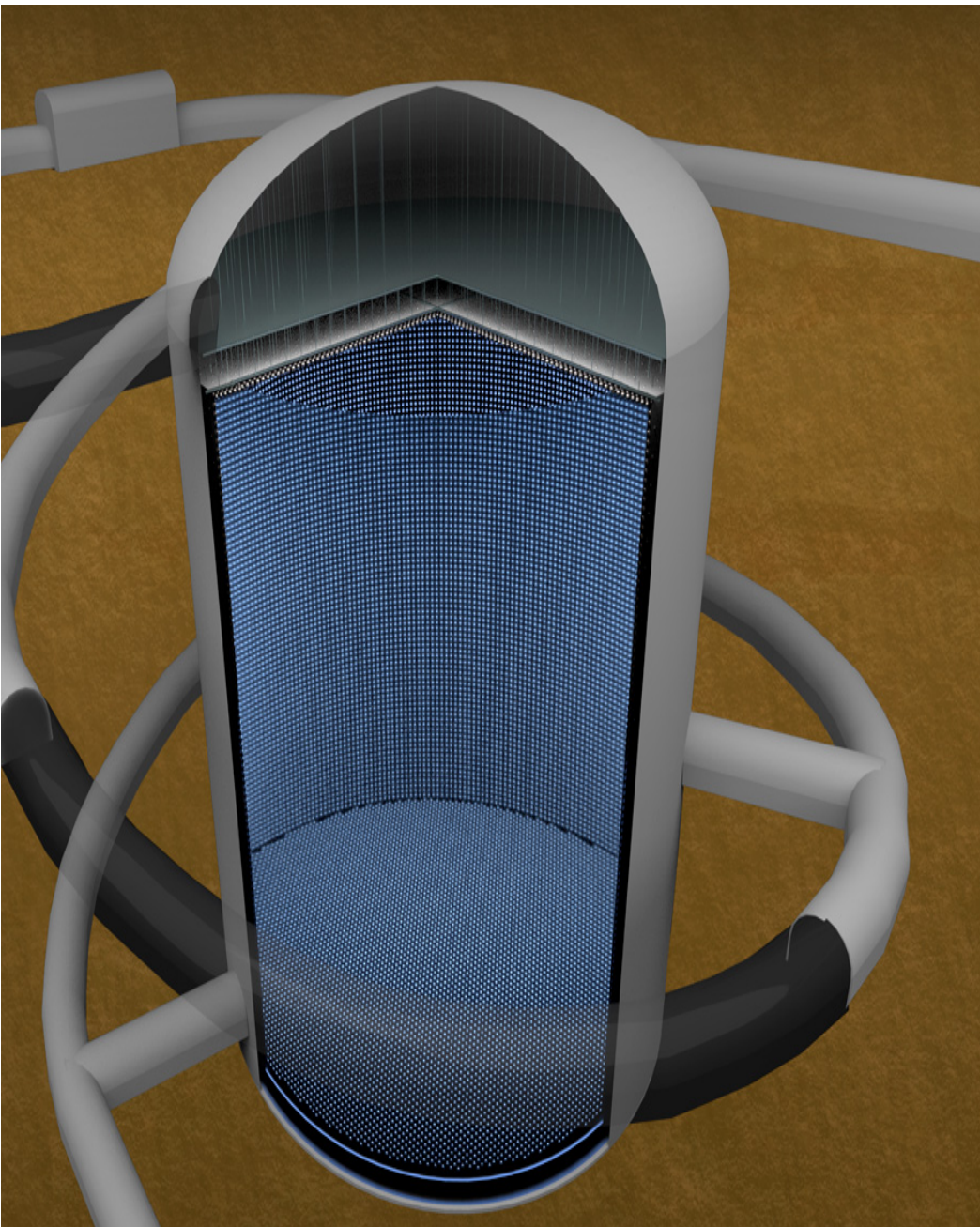
Takuya Tashiro (ICRR, University of Tokyo)
on behalf of Hyper-Kamiokande collaboration

September 2026
PPC2026 conference

Conceptual design of the HK detector

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Hyper-Kamiokande (HK) is the **new generation underground water Cherenkov detector** in Kamioka, Japan.

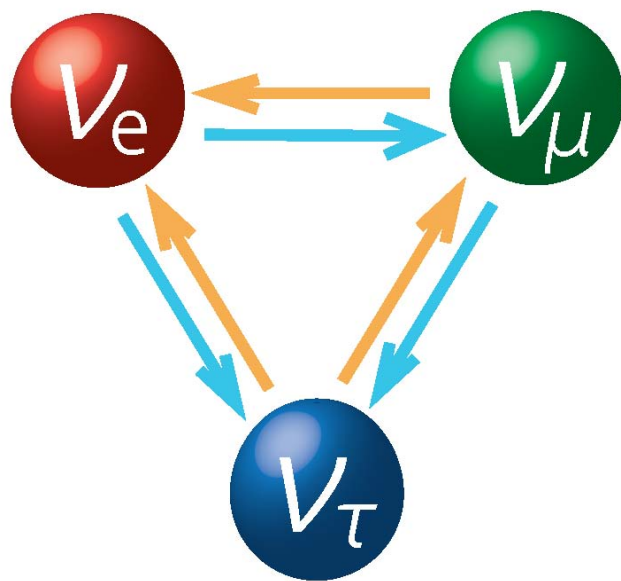


- ▶ A cylindrical tank with the diameter of 68 m and the depth of 71 m.
- ▶ Ultra-pure water of 258 kton is stored. The fiducial mass is 188 kton.
- ▶ Clean signal of neutrinos can be detected as it is built deep underground.
- ▶ PMTs are installed to detect the light caused by the Cherenkov radiation.
 - ▶ 50 cm PMTs for Inner-Detector
 - ▶ multi-PMTs for Inner-Detector
 - ▶ 3" PMTs for Outer-Detector

HK aims at revealing important physics feature

Neutrino oscillation

Oscillation properties will be measured based on **accelerator** and **atmospheric** neutrinos.



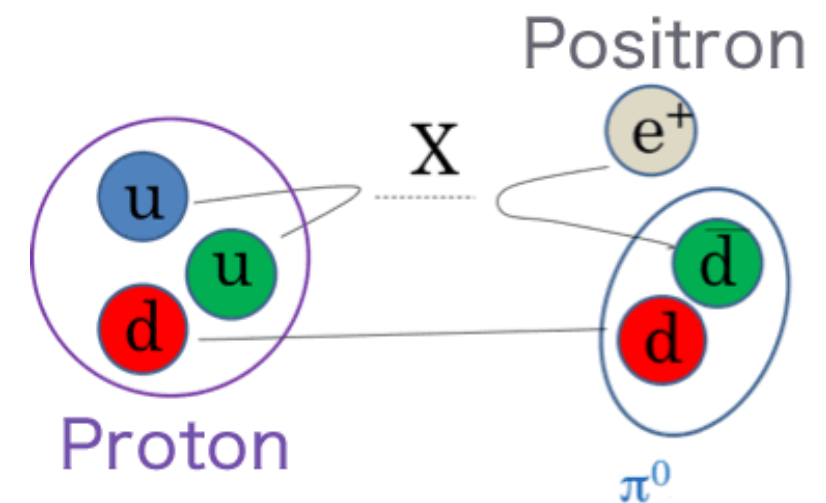
Neutrino astronomy

Solar, supernova, and **supernova relic** neutrinos will be explored for astronomical research.



Nucleon decay

Proton decay or **neutron decay** processes that violate baryon number will be searched to explore the GUT scale.



Neutrino oscillation

- The phenomenon of neutrino oscillation can be described by **6 parameters**.
 - 3 mixing angles: $\theta_{12}, \theta_{23}, \theta_{13}$
 - 1 CP phase: δ_{CP}
 - 2 mass squared differences:
 $\Delta m^2_{21} = m^2_2 - m^2_1$ and $\Delta m^2_{32} = m^2_3 - m^2_2$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos \theta_{23} & \sin \theta_{23} \\ 0 & -\sin \theta_{23} & \cos \theta_{23} \end{pmatrix} \begin{pmatrix} \cos \theta_{13} & 0 & e^{-i\delta_{CP}} \sin \theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}} \sin \theta_{13} & 0 & \cos \theta_{13} \end{pmatrix} \begin{pmatrix} \cos \theta_{12} & \sin \theta_{12} & 0 \\ -\sin \theta_{12} & \cos \theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

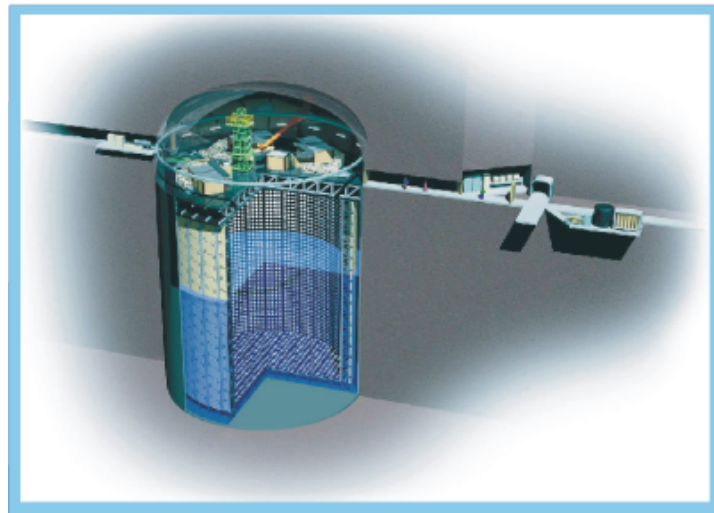
- The value of δ_{CP} and sign of Δm^2_{32} are not yet determined.

Upgrade plan for HK long-baseline

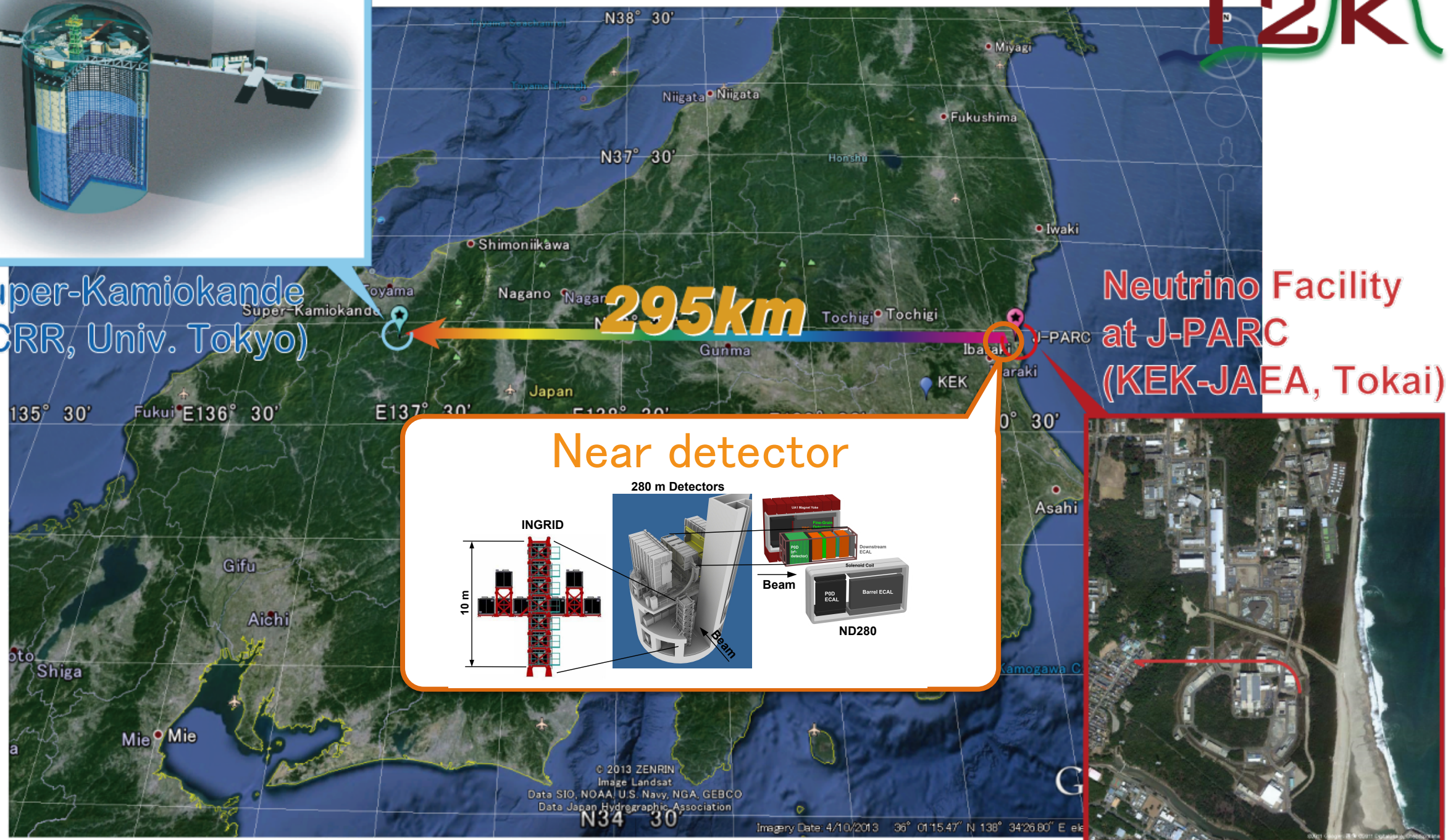
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Ongoing experiment: T2K

T2K

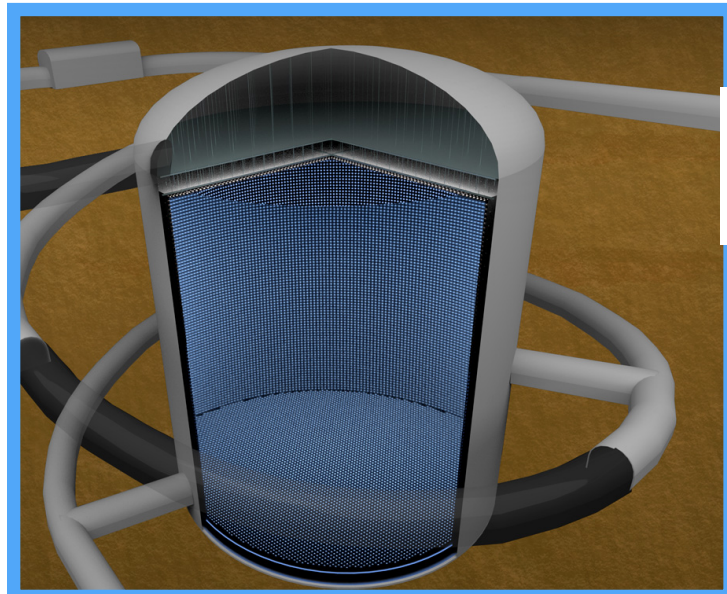


Super-Kamiokande
(ICRR, Univ. Tokyo)



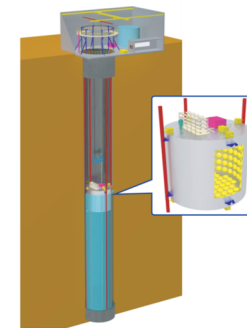
Upgrade plan for HK long-baseline

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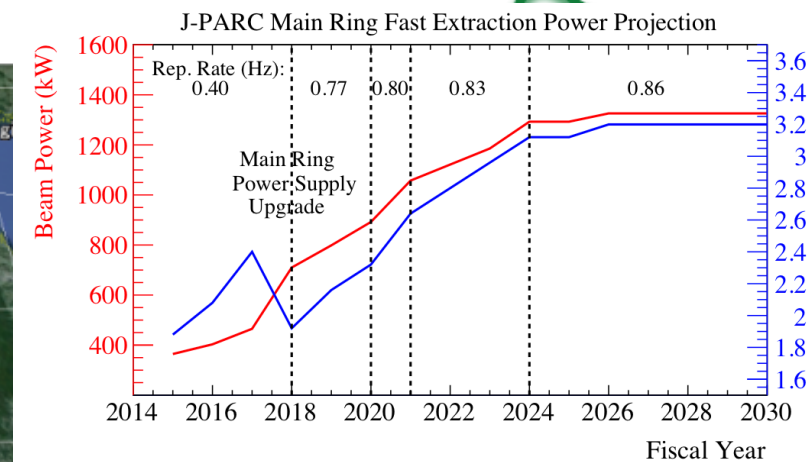


New intermediate water-Cherenkov detector (IWCD)

HK will be used as the far detector

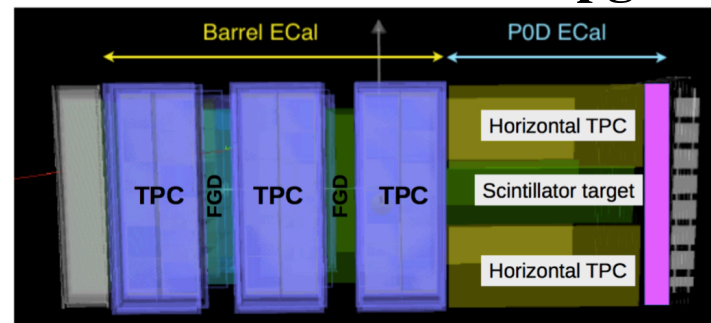


HK long-baseline



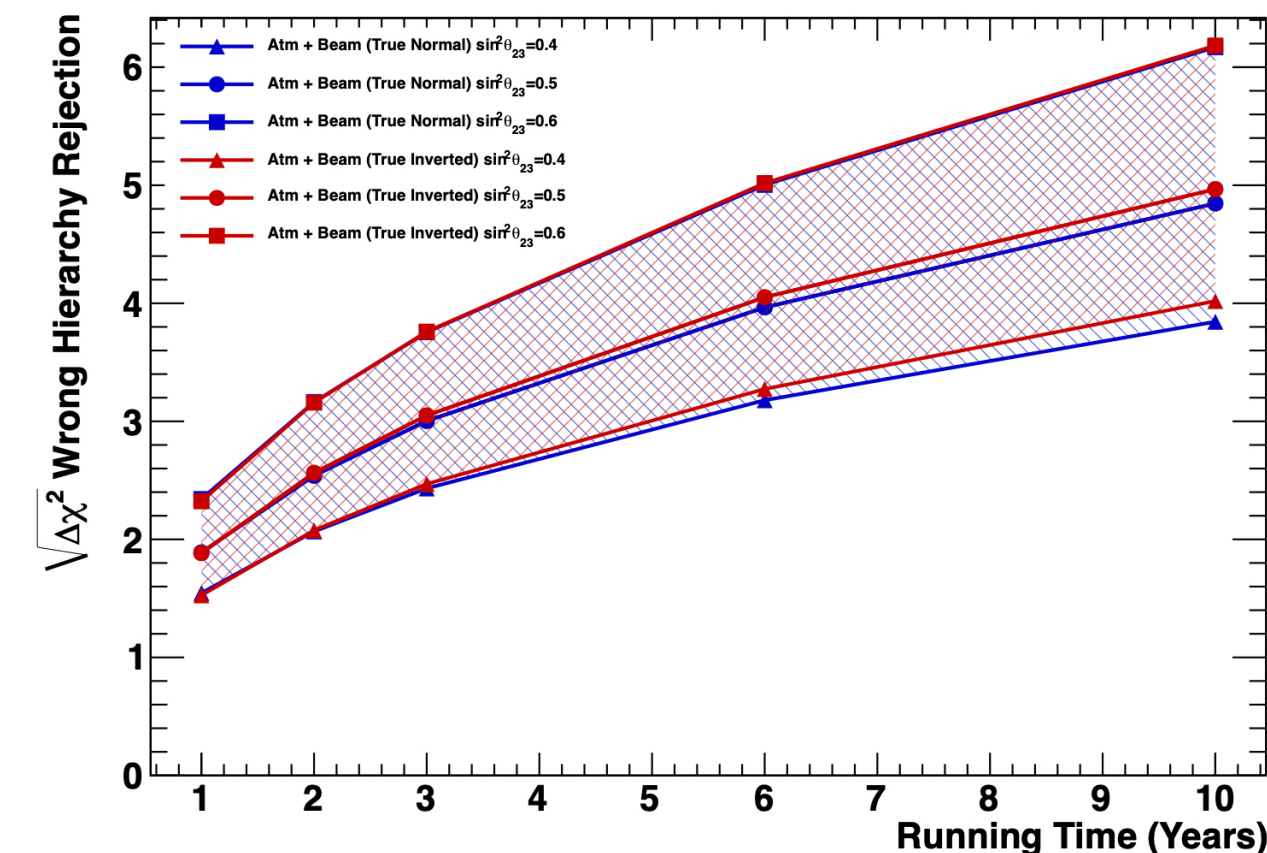
Beam power will be upgraded to **1.3 MW**

Near detector has been upgraded.

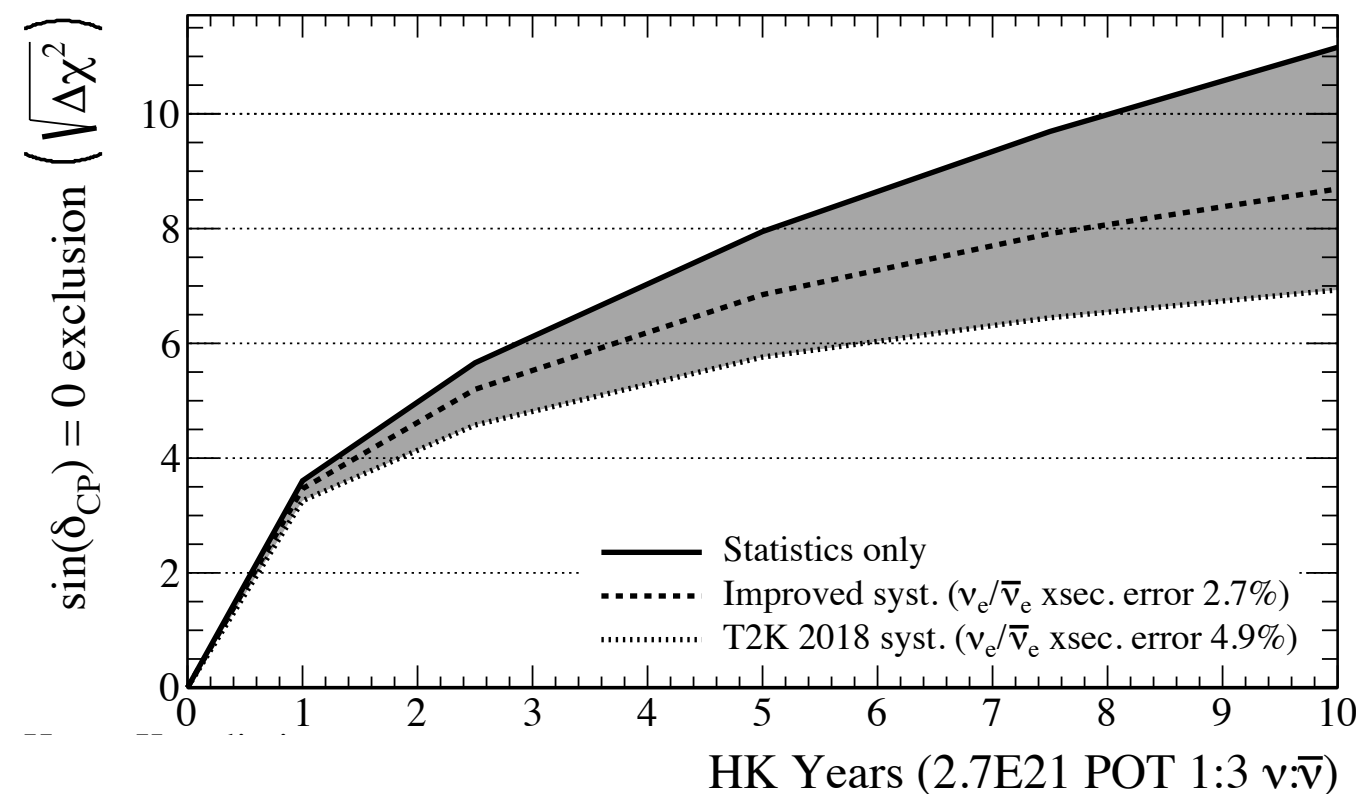


Expected sensitivity on neutrino oscillation ⁷

- ▶ The atmospheric and accelerator measurements will be combined to determine the oscillation parameters.
- ▶ Within 10 years of operation, the mass hierarchy is expected to be determined and CP conservation can be excluded if the violation is large.

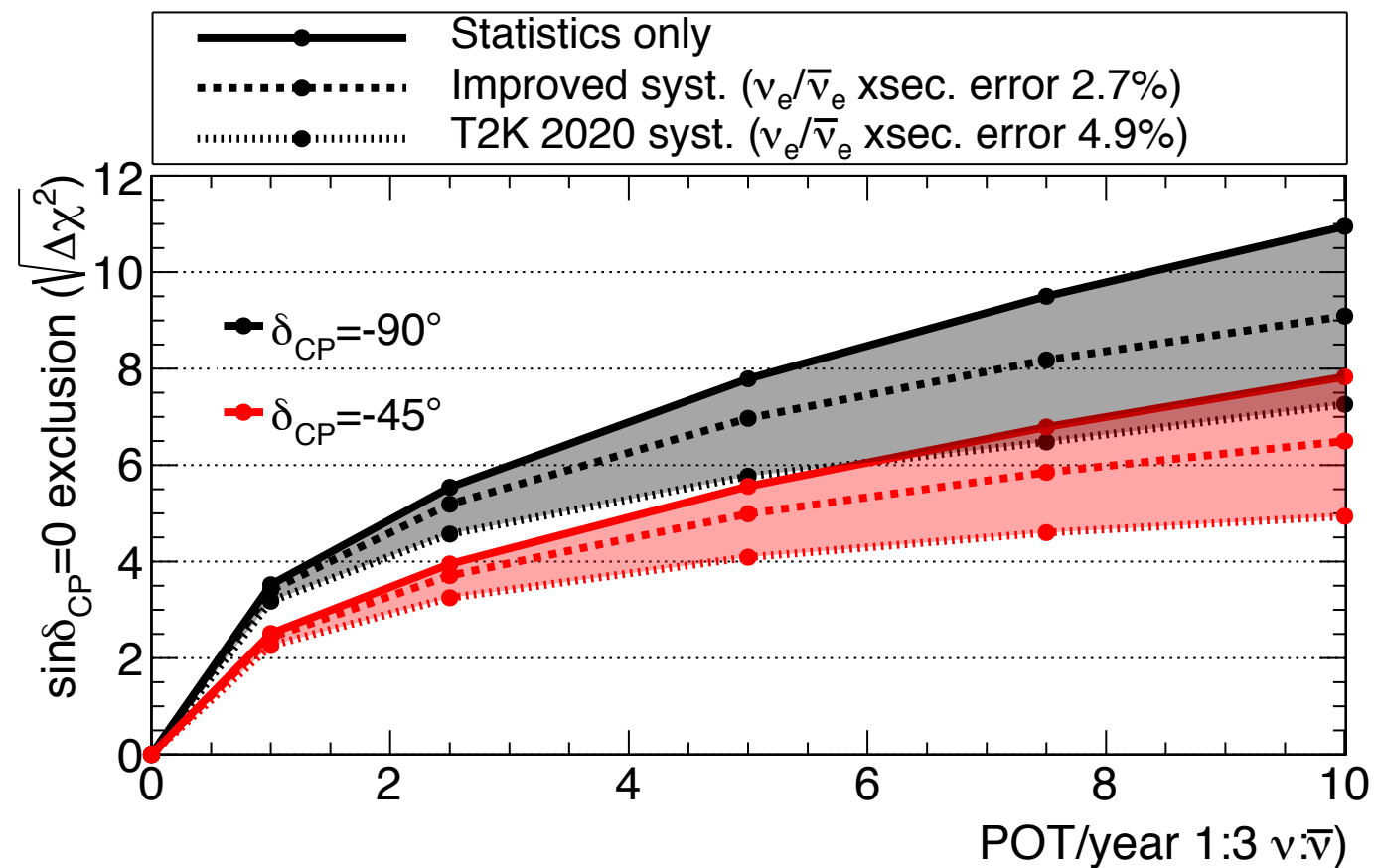
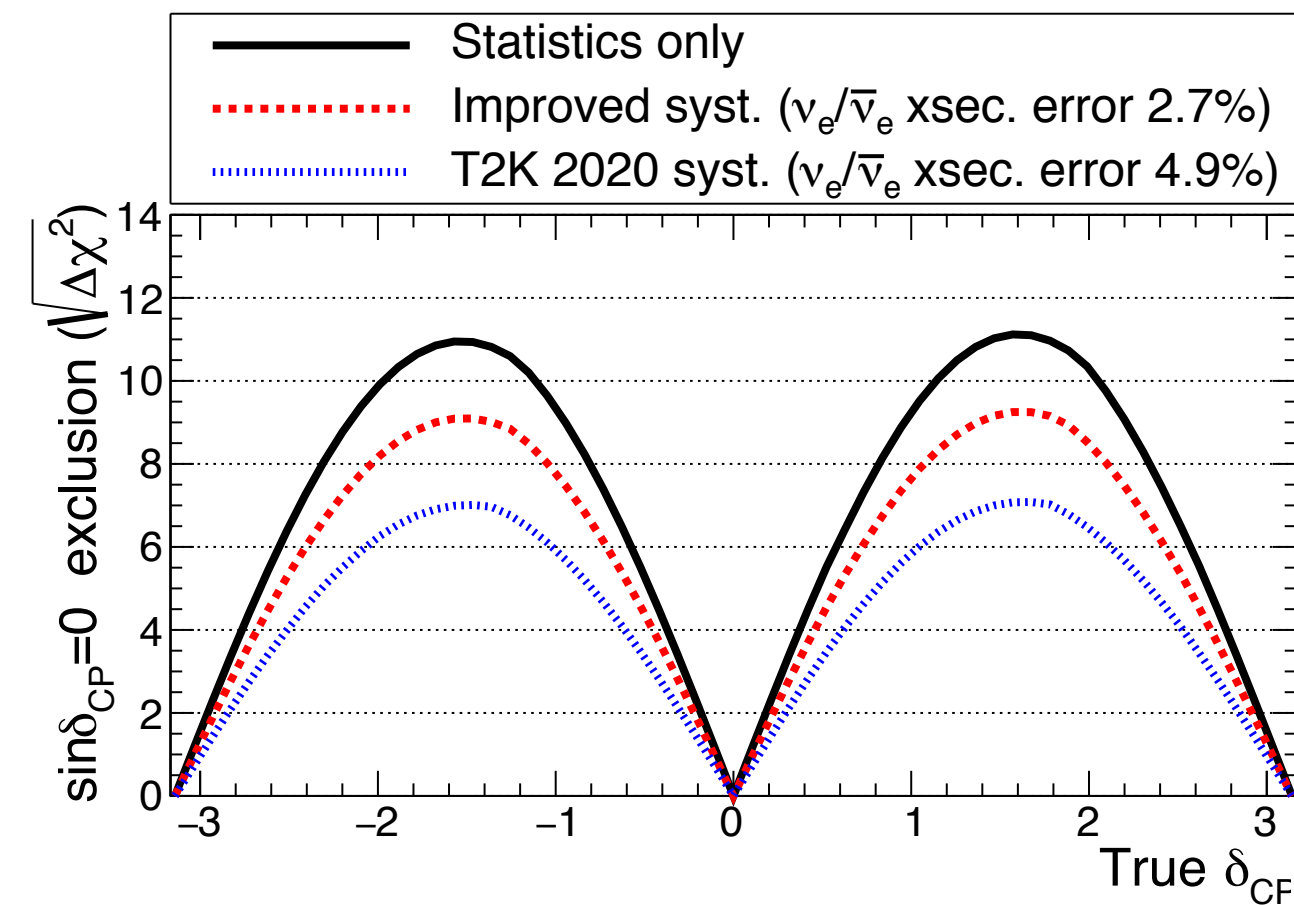


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Expected sensitivity on δ_{CP}

With the larger detector and more powerful beam, the $\delta_{CP} = 0$ hypothesis can be rejected by 5σ within 3 years of operation if the true $\delta_{CP} = -90^\circ$.

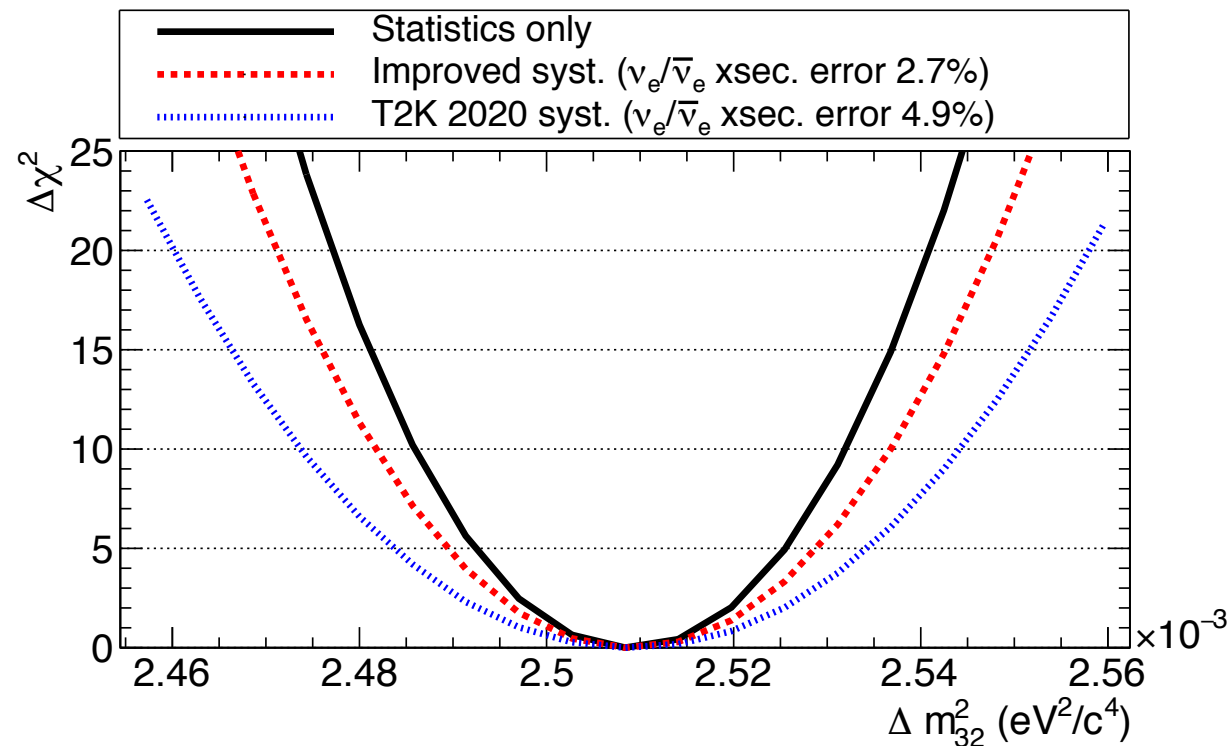
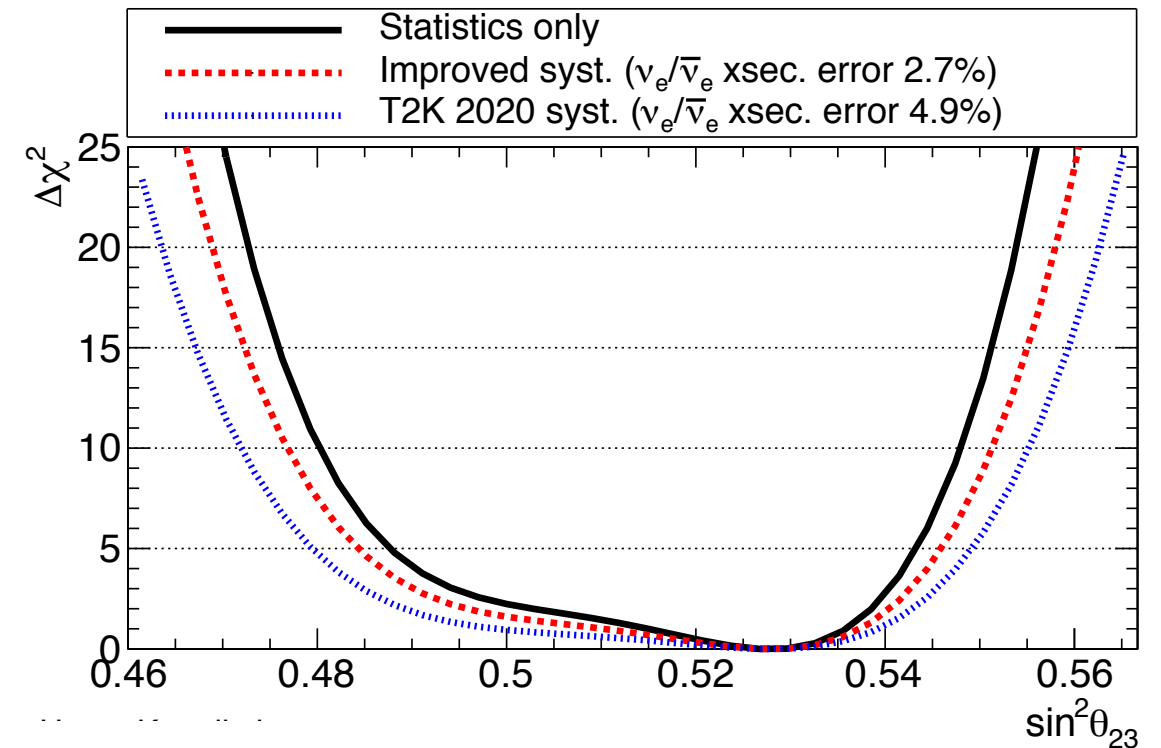


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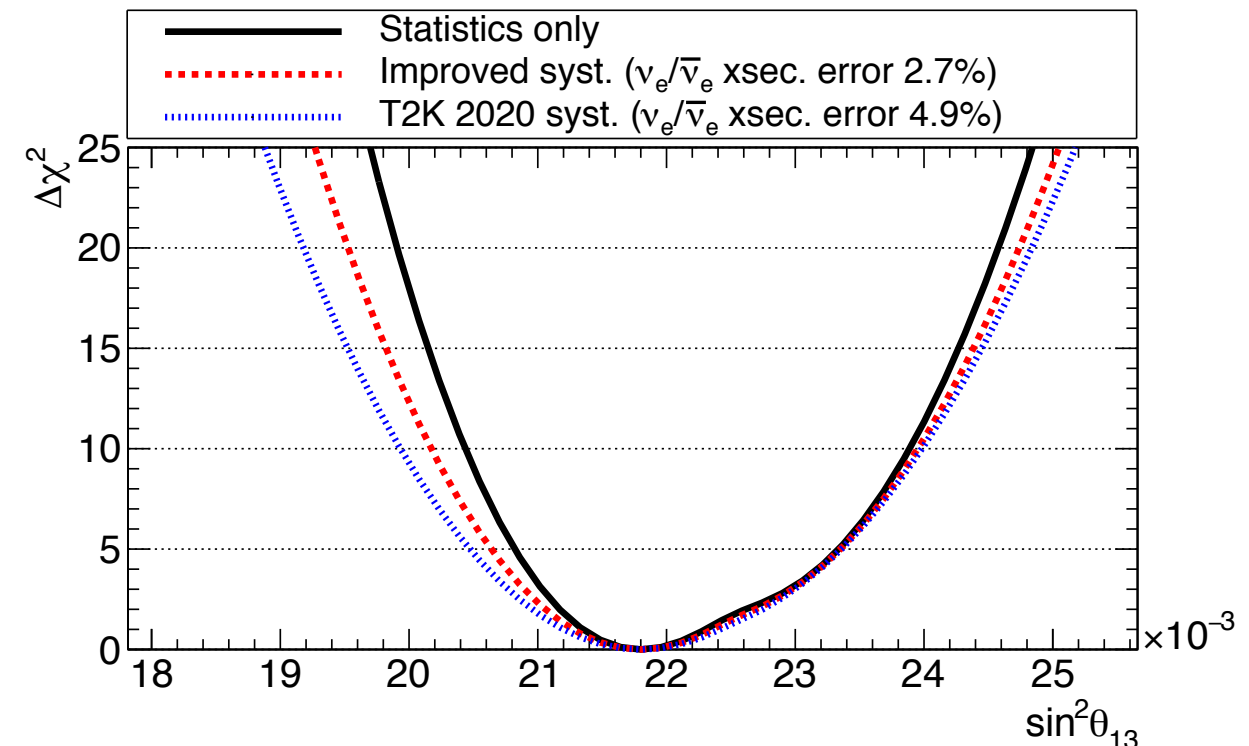
I^2/c^4

Expected sensitivity on oscillation parameters⁹

Other oscillation parameters can be constrained by the accelerator neutrino.



True normal ordering (known), 10 years (2.7×10^{22} POT 1:3 $\nu:\bar{\nu}$)
 $\sin^2\theta_{13}=0.0218 \pm 0.0007$, $\sin^2\theta_{23}=0.528$, $\Delta m_{32}^2=2.509 \times 10^{-3} \text{ eV}^2/c^4$, $\delta_{CP}=-1.601$

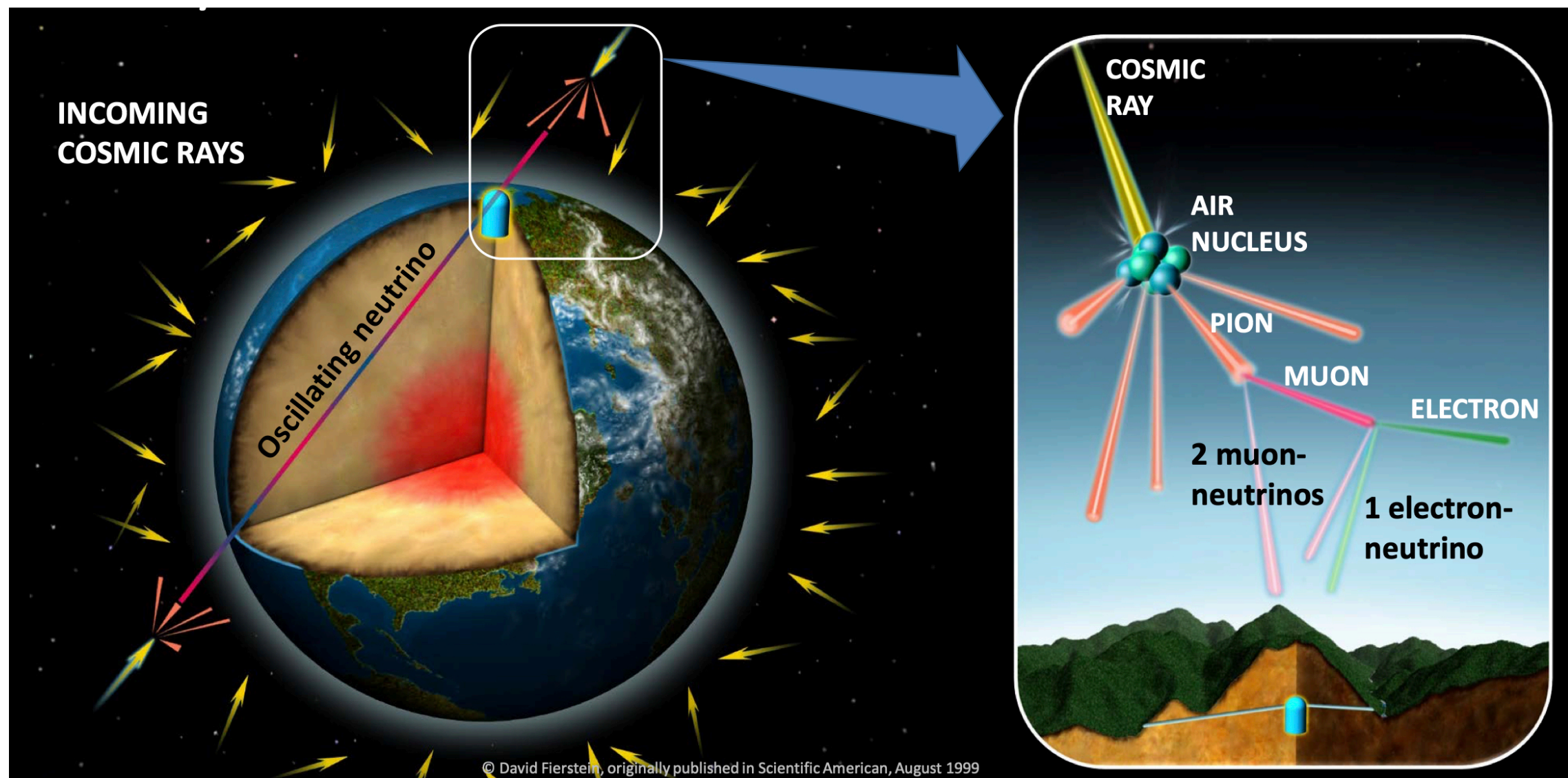


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Atmospheric neutrinos

- ▶ **Atmospheric neutrinos** are generated by interactions between primary cosmic ray and atmospheric nucleus.
- ▶ Wide range of energies and path length can be used to measure oscillation parameters.

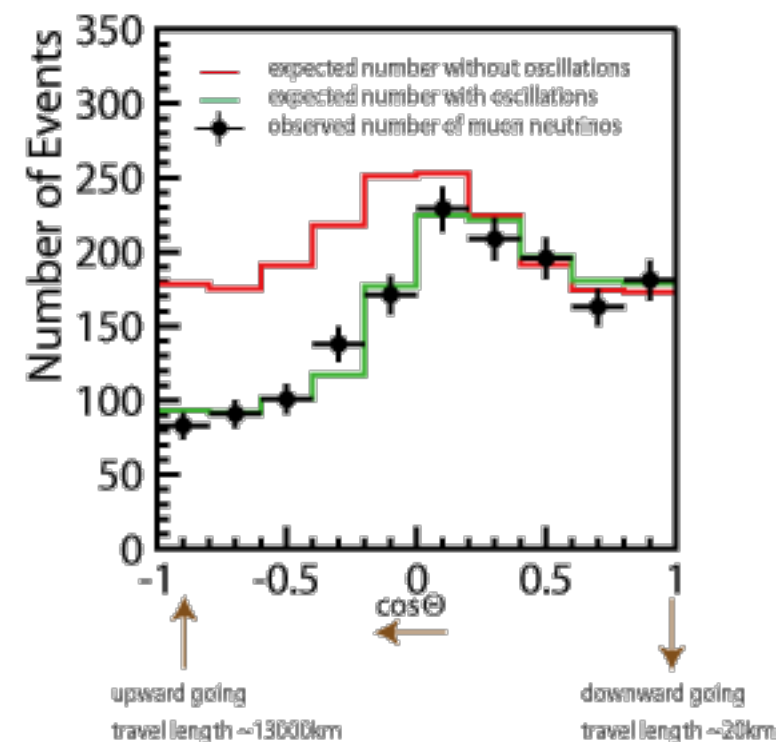


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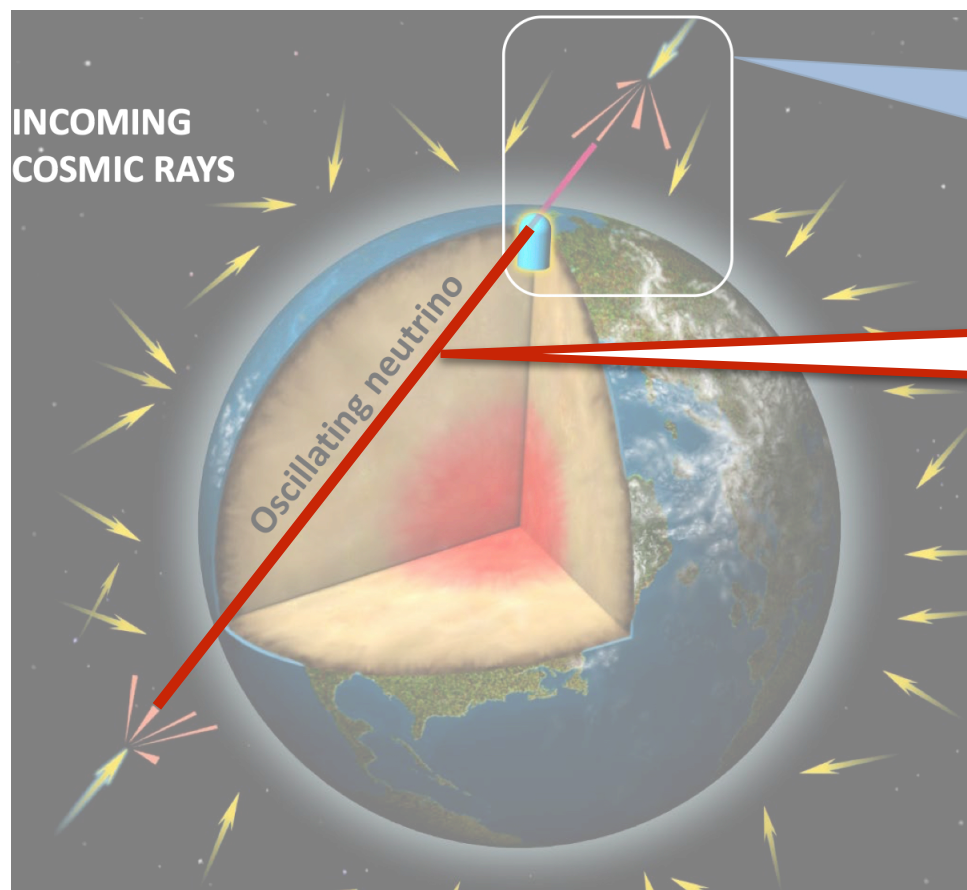
Neutrino oscillation was first discovered by Super-Kamiokande using atmospheric neutrinos.



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Atmospheric neutrinos

- ▶ One of the most important topics in the atmospheric neutrinos study is the mass hierarchy.
 - ▶ Neutrinos mass ordering is still unknown.
 - ▶ Normal hierarchy: $m_2 < m_3$.
 - ▶ Inverted hierarchy: $m_2 > m_3$.

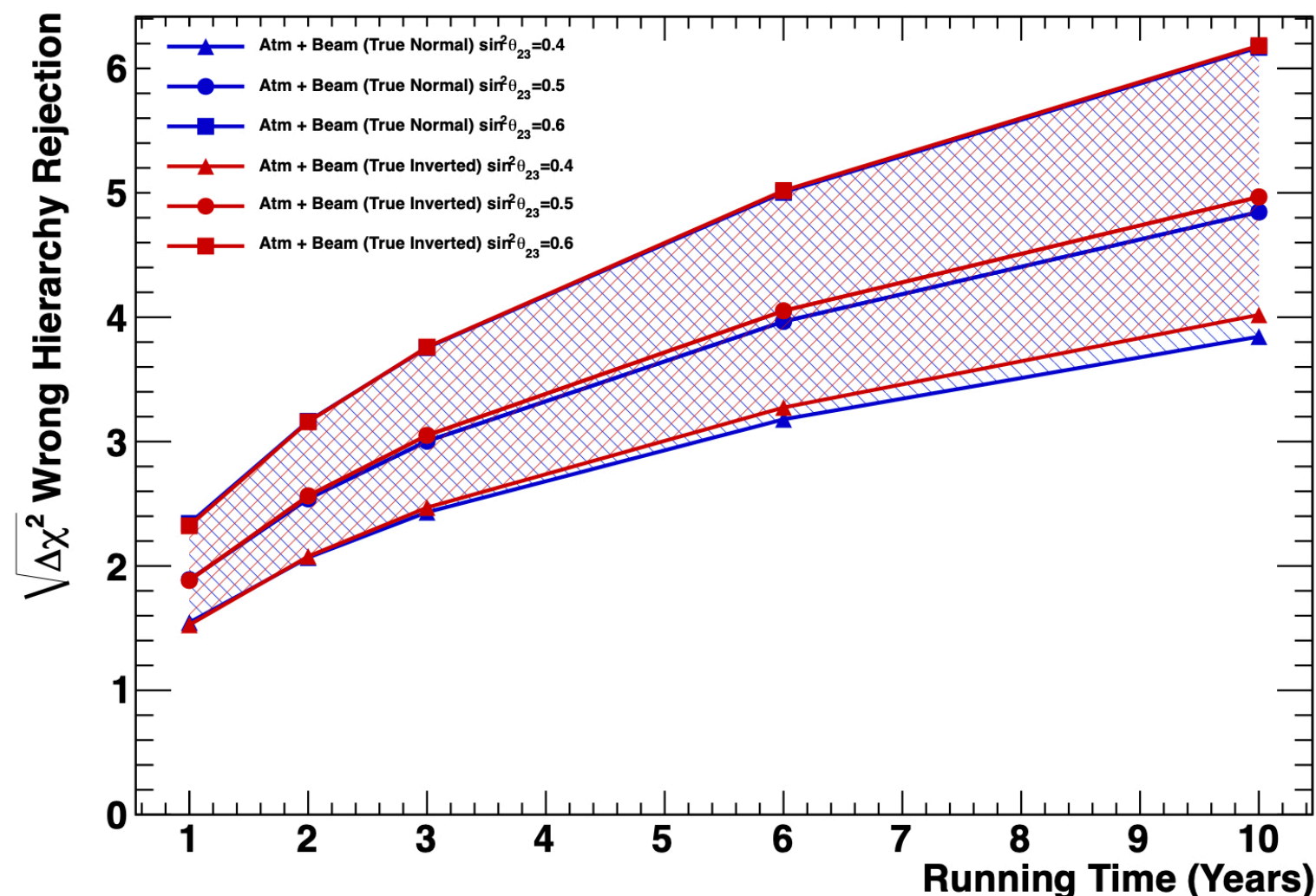


- ▶ Neutrinos penetrating the Earth are affected by the matter effect.
- ▶ Normal hierarchy: $\nu_\mu \rightarrow \nu_e$ is enhanced.
- ▶ Inverted hierarchy: $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ is enhanced.

- ▶ Comparison between neutrino and anti-neutrino oscillation can be used to determine the hierarchy.

Combining atmospheric and beam neutrino ¹³

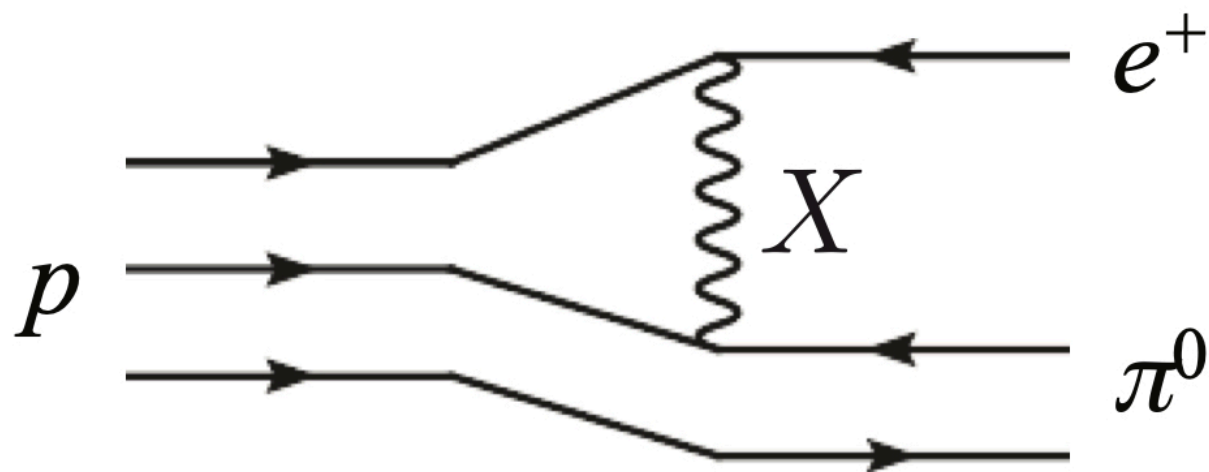
- ▶ The atmospheric and accelerator measurements will be combined to determine the oscillation parameters.
- ▶ The mass hierarchy is expected to be determined within < 10 years of operation.



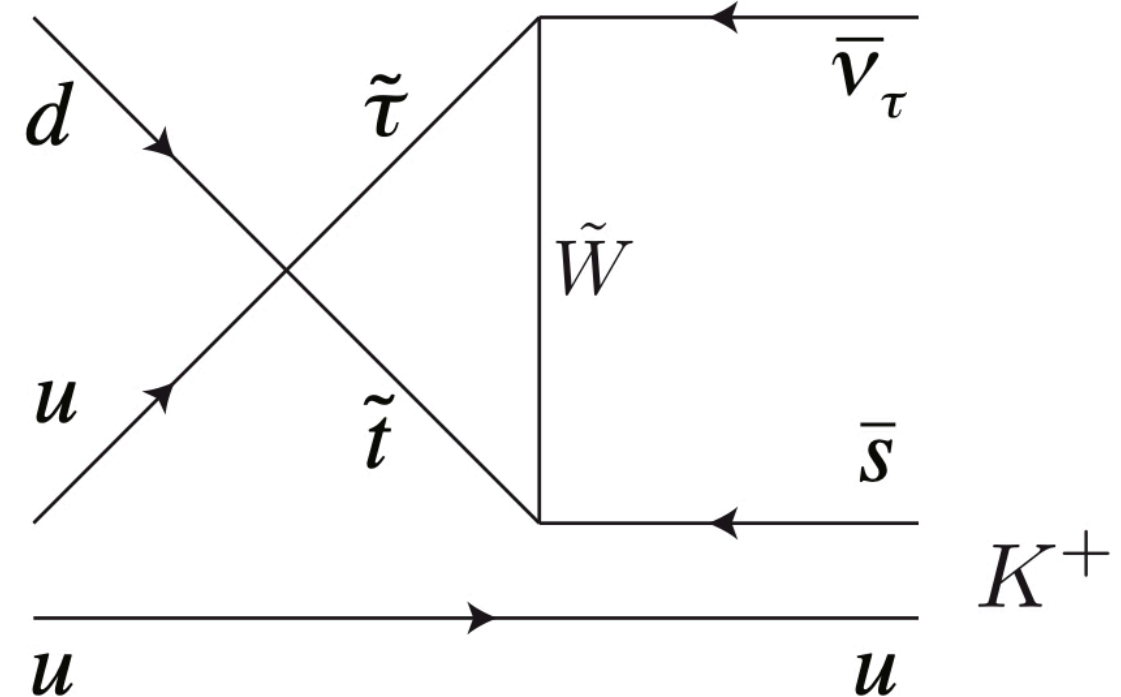
Nucleon decay searches

- The nucleon decay phenomena, which violate the baryon number conservation, are one of the main physics goals in HK.
- The search by HK is expected to reach the proton lifetime predicted by various theories.
- HK has sensitivity to various decay modes.

$p \rightarrow e^+ \pi^0$ diagram

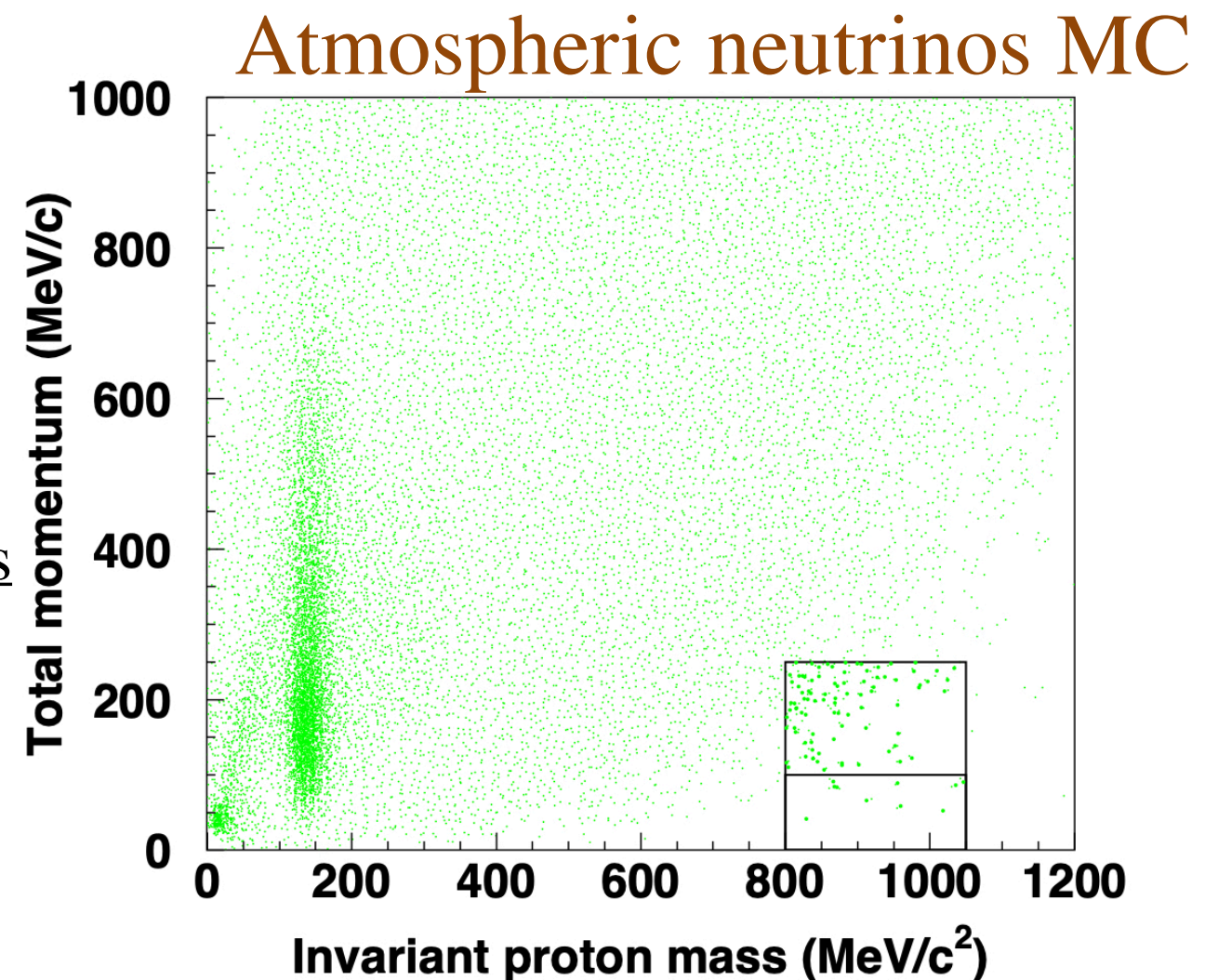
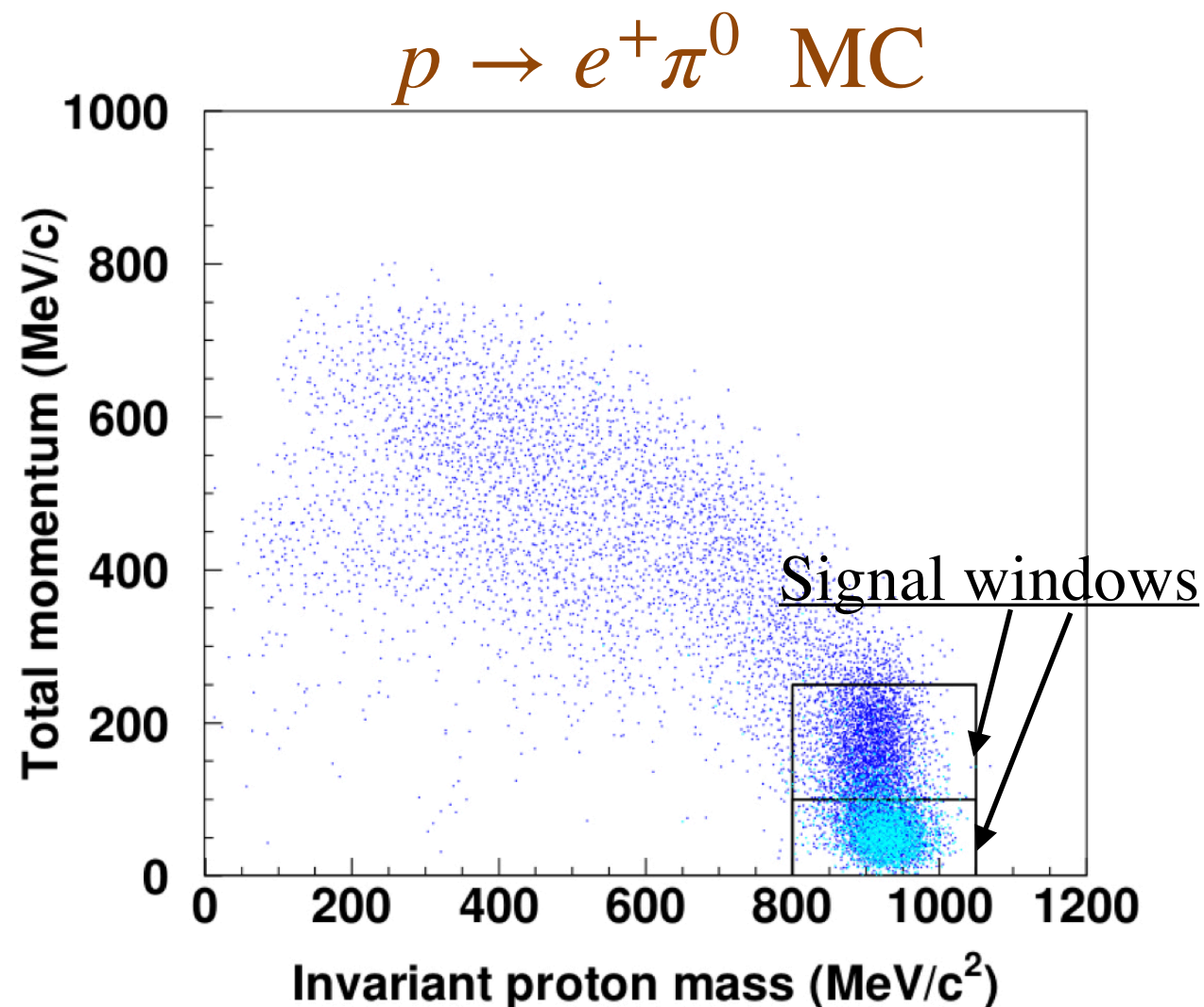


$p \rightarrow K^+ \bar{\nu}$ diagram



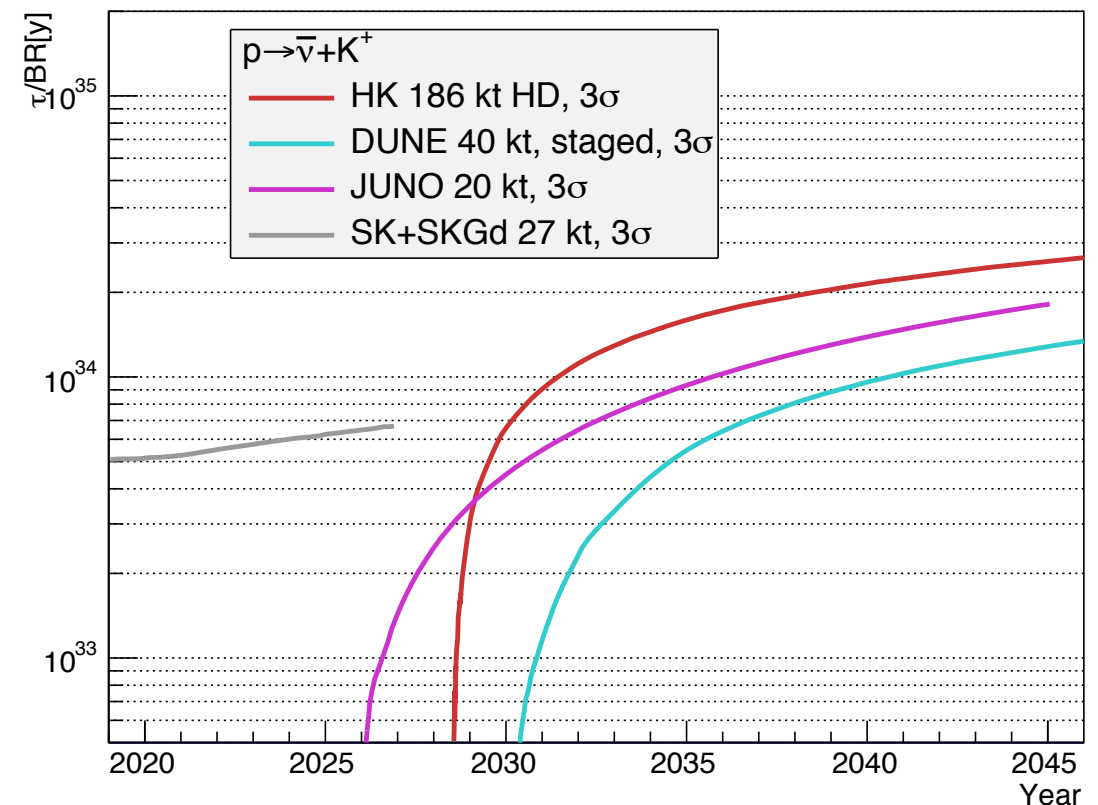
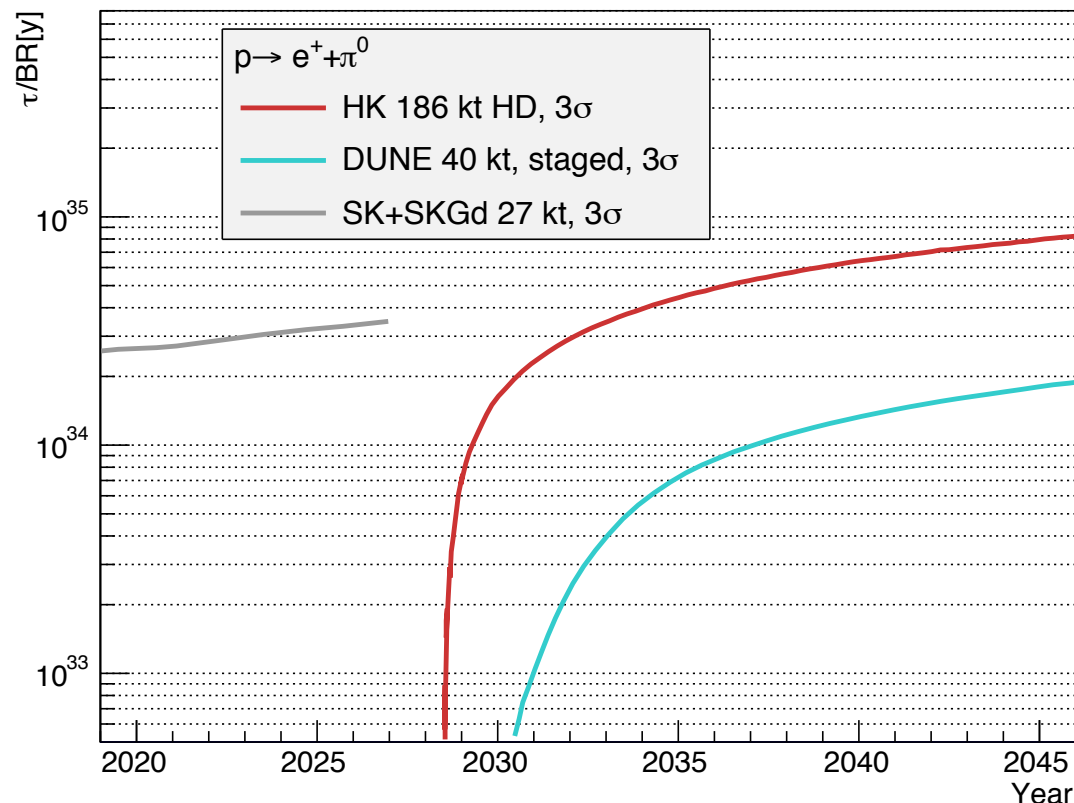
Nucleon decay searches

- In the nucleon decay searches in HK, event selection based on the rings kinematics is applied.
- After the selection, **the invariant mass** and **total momentum** are calculated using all the reconstructed rings and then the number of events in signal windows is calculated.



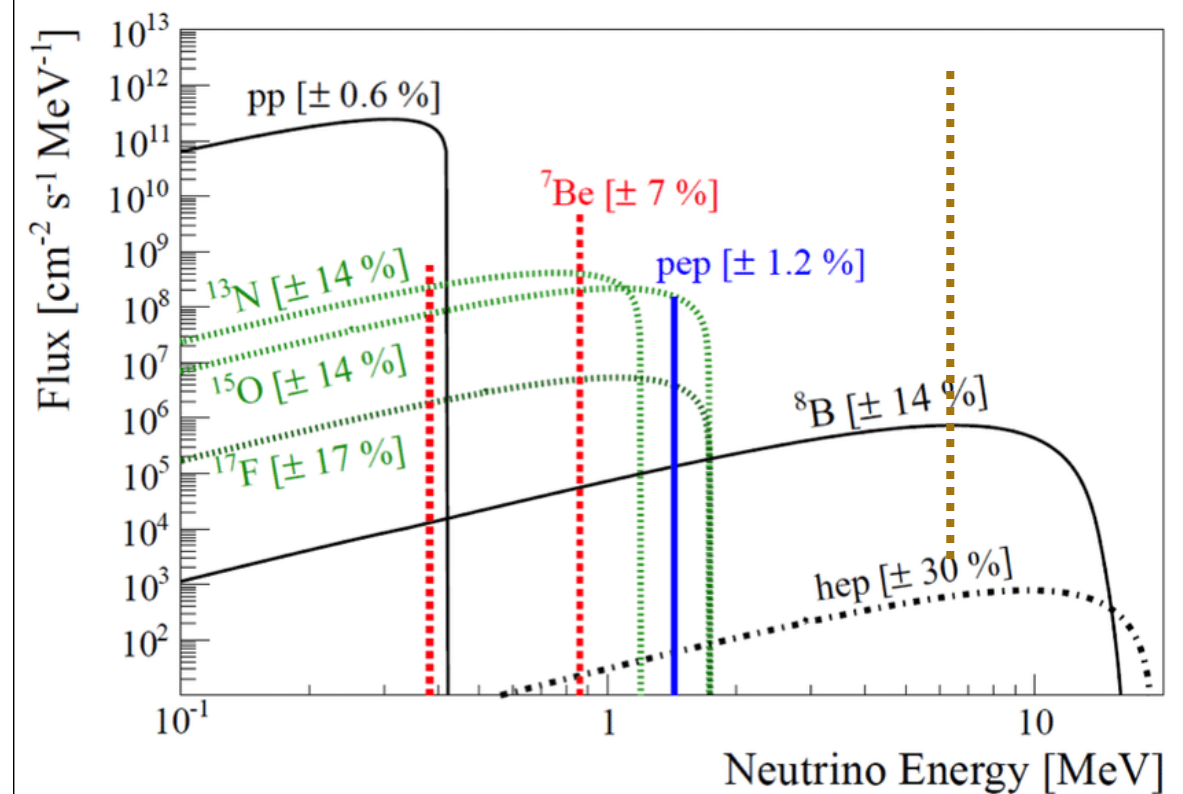
Expected sensitivity on nucleon decay searches¹⁶

- In the nucleon decay searches in HK, event selection based on the rings kinematics is applied.
- After the selection, **the invariant mass** and **total momentum** are calculated using all the reconstructed rings and then the number of events in signal boxes is calculated.
- **The sensitivity can reach up to 5×10^{34} (1×10^{34}) years of lifetime in $e^+ \pi^0 (\bar{\nu} K^+)$ mode within 5 years of operation.**



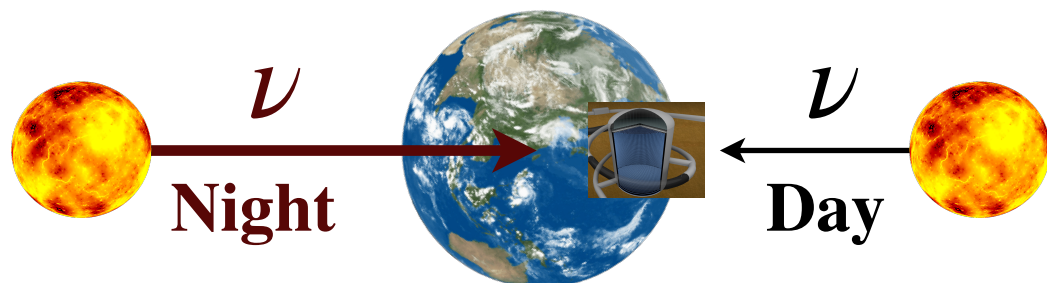
Solar neutrinos

- Solar neutrinos are the neutrinos originated from nuclear reactions in the Sun.
- The measurement of solar neutrinos include several important topics.



Day/Night (D/N) asymmetry

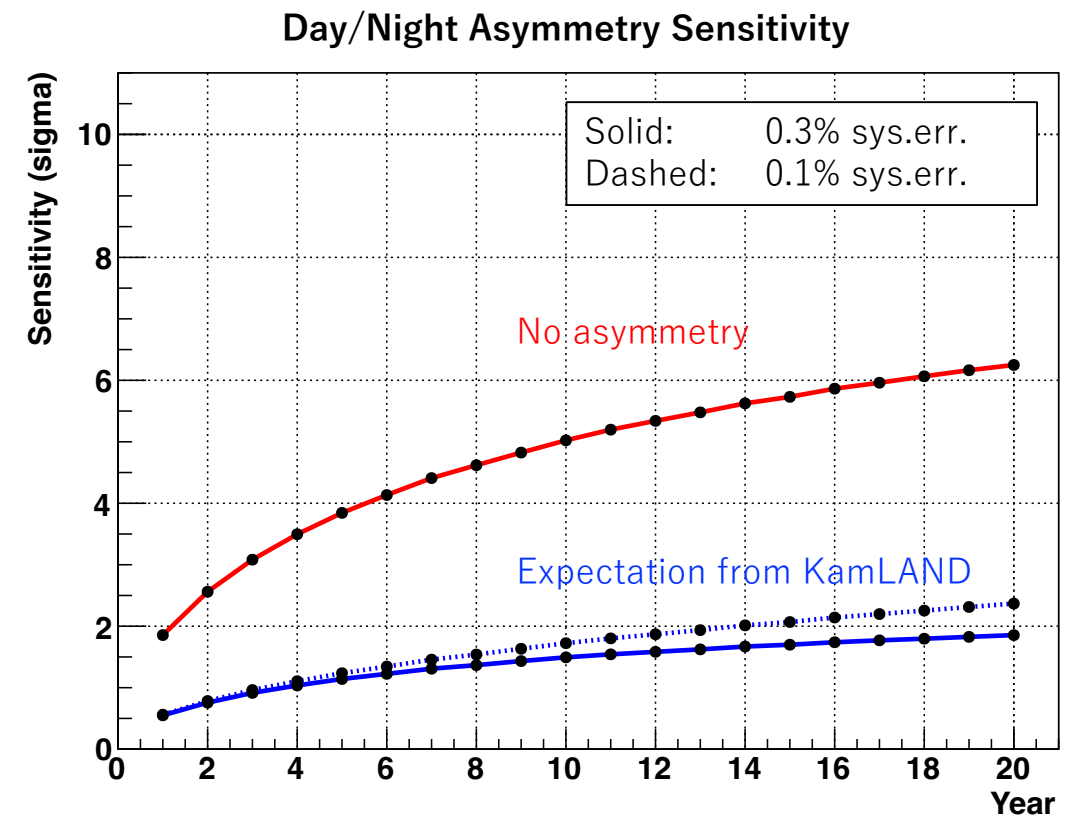
- The terrestrial matter effect can result in **D/N asymmetry**.
- This can affect Δm_{21}^2 measurement.



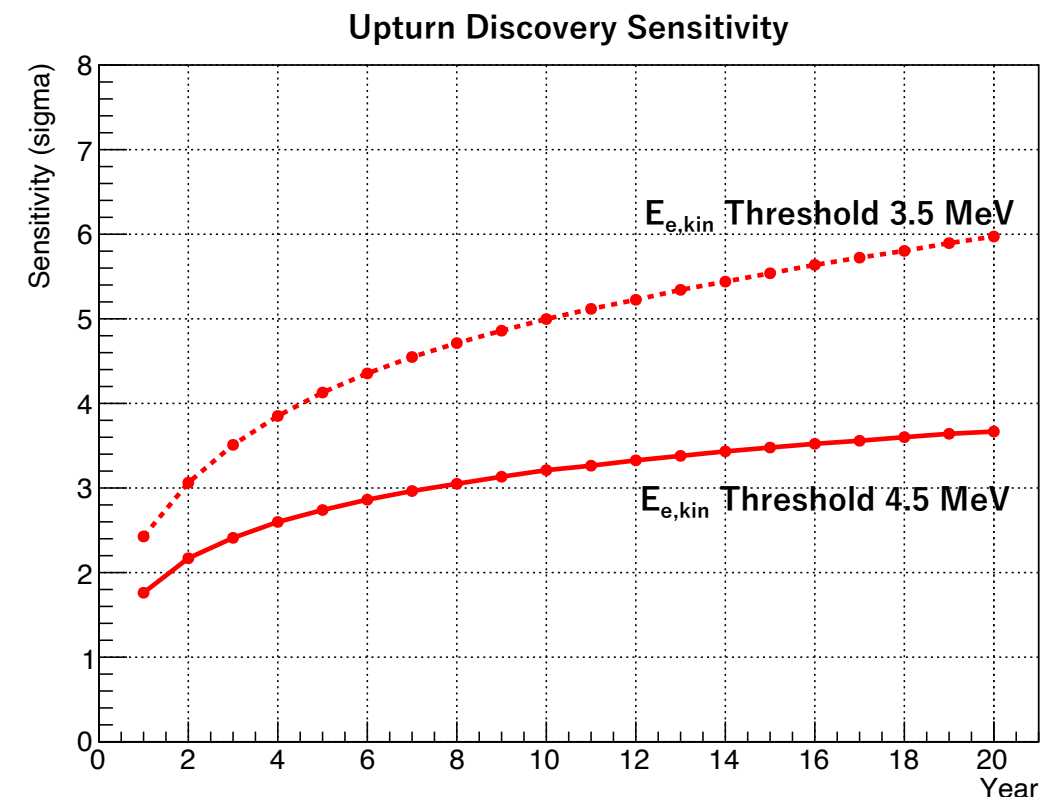
Upturn of the spectrum

- Upturn is the variation of the ν_e survival probability between the vacuum and MSW dominated energy region.
- This is not observed yet and can be a hint for BSM physics.

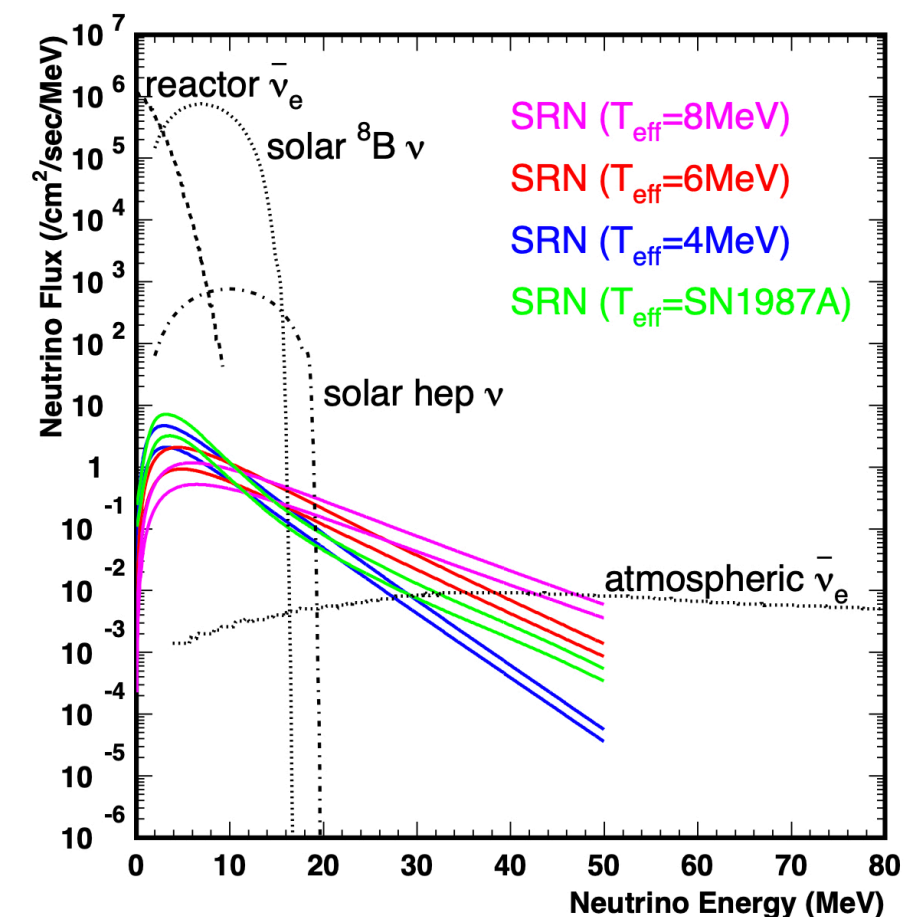
- ▶ In the D/N asymmetry is expected to be observed with **> 5 σ** after 10 years of operation in the case of $\Delta m_{21}^2 = 6.11 \times 10^{-5} \text{eV}^2$. In the case of $\Delta m_{21}^2 = 7.54 \times 10^{-5} \text{eV}^2$ (KamLAND) best value, the sensitivity is expected to be smaller.



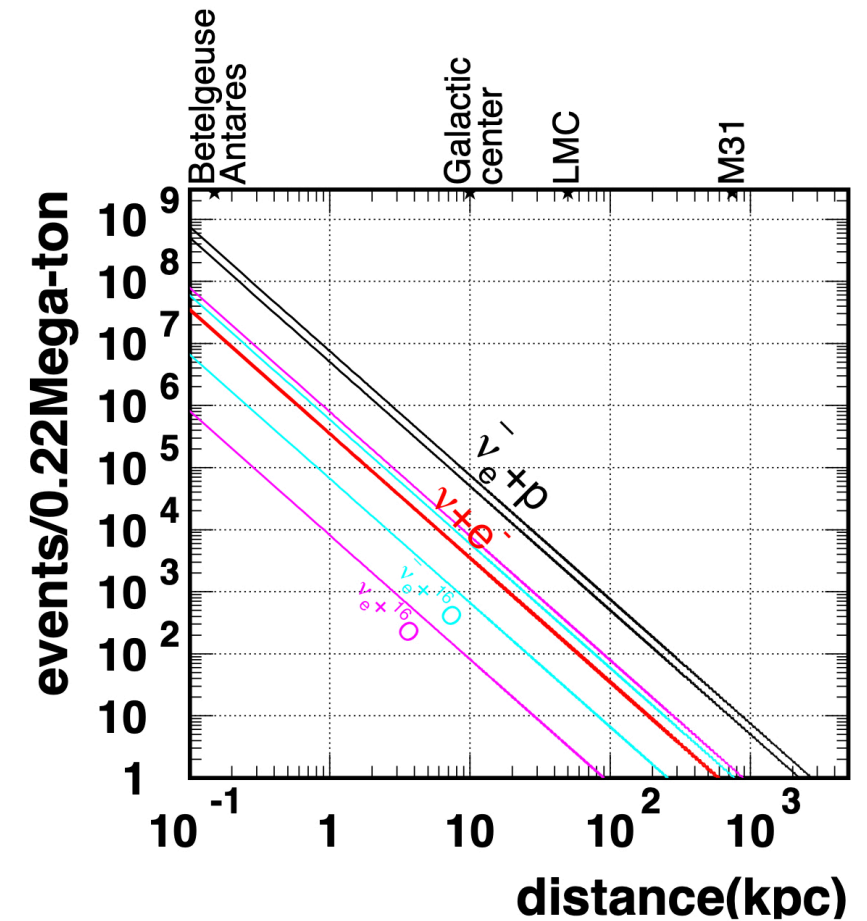
- ▶ In the upturn analysis, it is expected that **the sensitivity exceeds 5(3) σ** after 10 operation years with the threshold of 3.5(4.5) MeV.



- ▶ **Supernova (SN) neutrinos** are emitted by core-collapse SN.
 - ▶ Large amount of neutrinos is expected to be detected by HK if a SN happens in our galaxy (distance of 10 kpc).
 - ▶ 11 events were observed by Kamiokande (2.14 kton) in SN1987a (distance of 50 kpc)
- ▶ **Supernova relic neutrinos (SRN)** are the diffused neutrinos emitted from past SNe.
 - ▶ The existence of SRN is widely accepted, but it has not been observed yet.
 - ▶ The spectra of SRN are predicted by various models.
 - ▶ The measurement of SRN can be a new tool to explore the history of the universe.



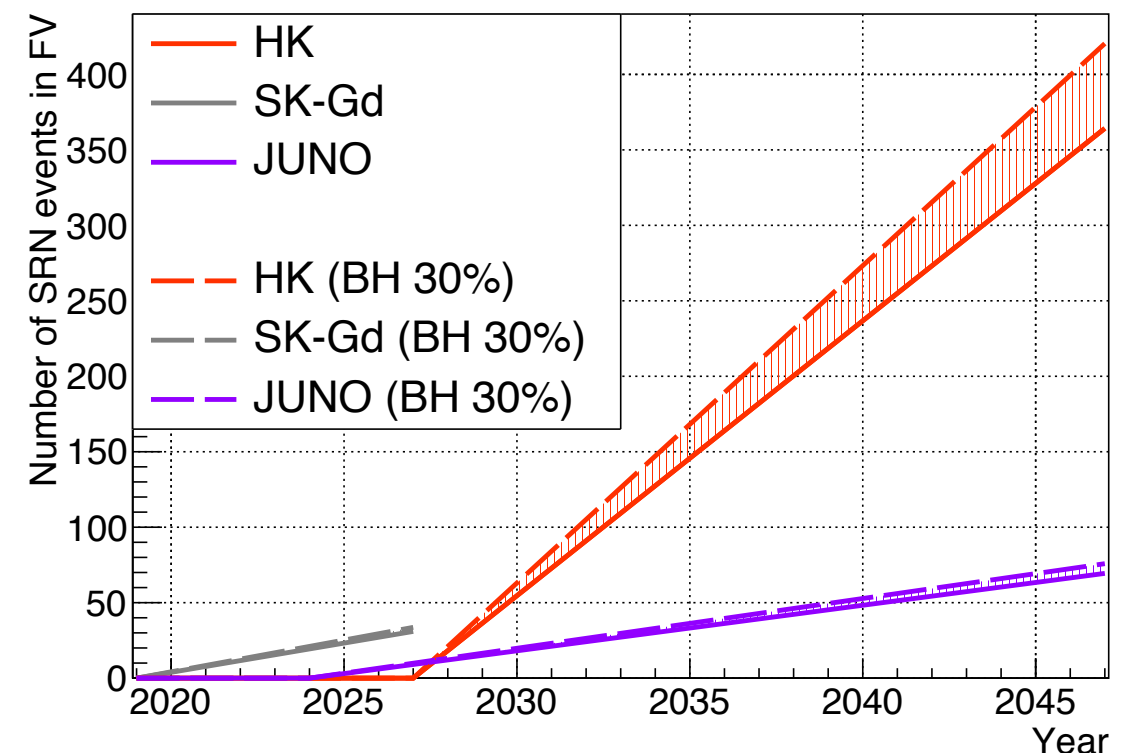
- ▶ The event rate of SR neutrinos is computed as a function of the distance between the Earth and SN.
 - ▶ $O(10k)$ events if a SN happens in the galactic center.
 - ▶ $O(10)$ events if a SN happens in M31 (Andromeda galaxy, ~ 750 kpc away).



- ▶ Prediction of the number of detected SRN events is calculated.

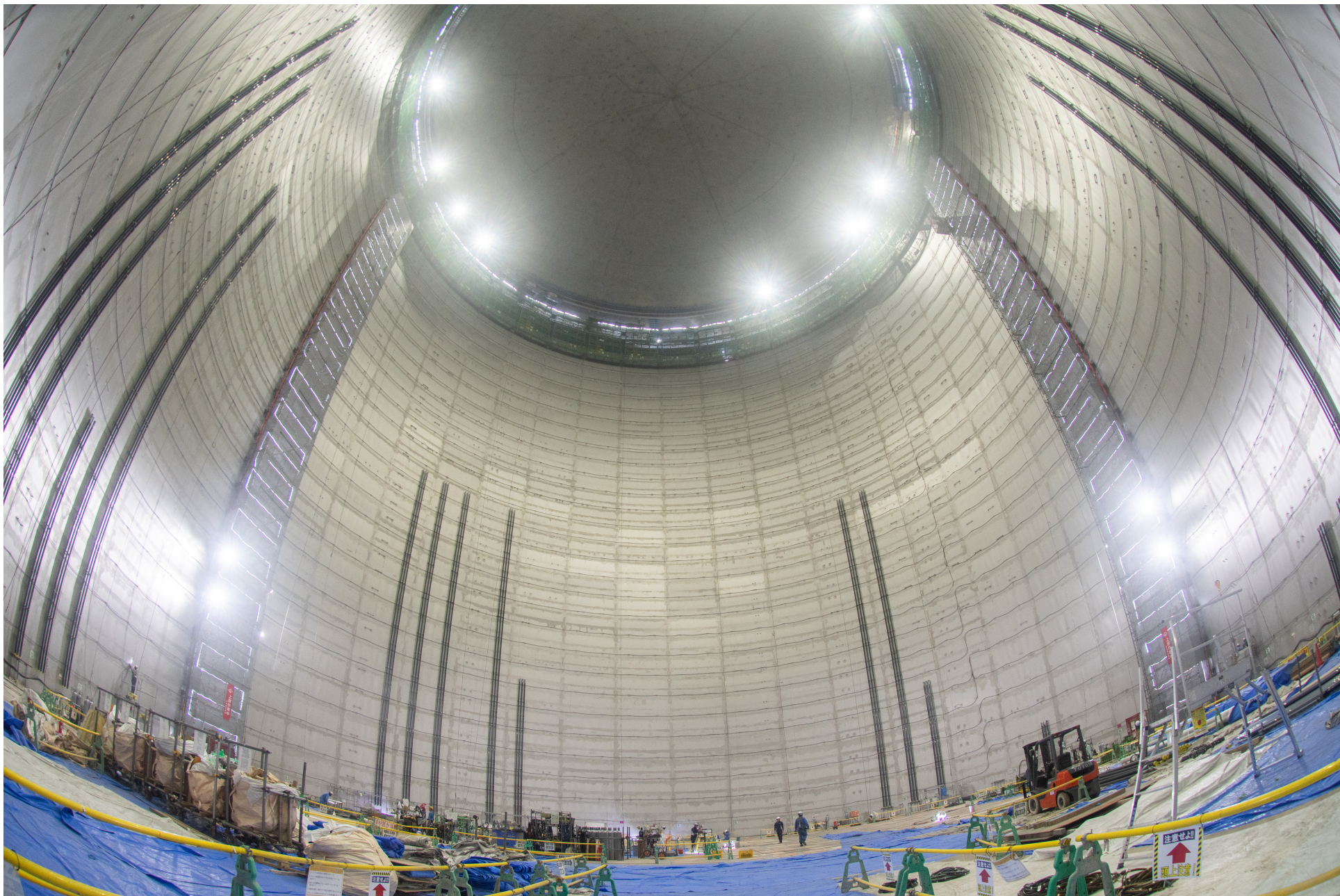
Two assumptions are considered:

- ▶ All the core-collapse supernovae emits neutrinos
- ▶ 30% of the supernovae from blackhole emits higher energy neutrinos.

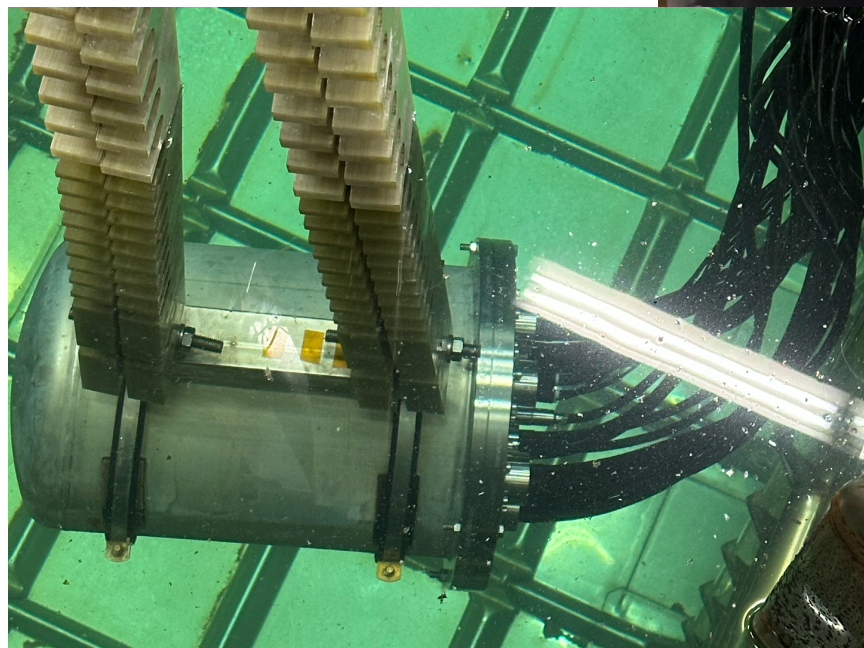
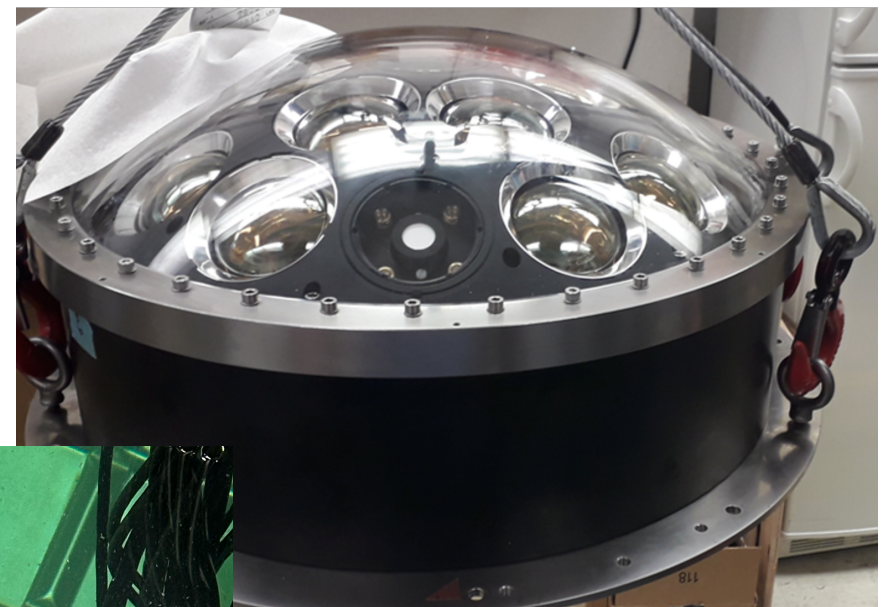


Schedule and status

HK operation is scheduled to start in 2028.
Construction and preparation is ongoing.



- **Cavern&tank**
 - Excavation and tank lining completed.
- **ID 50cm PMTs**
 - Purchase of the scheduled number of PMTs completed.
- **Multi-PMTs and OD PMTs:**
 - Production is ongoing.
- **Electronics:**
 - R&D completed.
 - Part procurement is ongoing



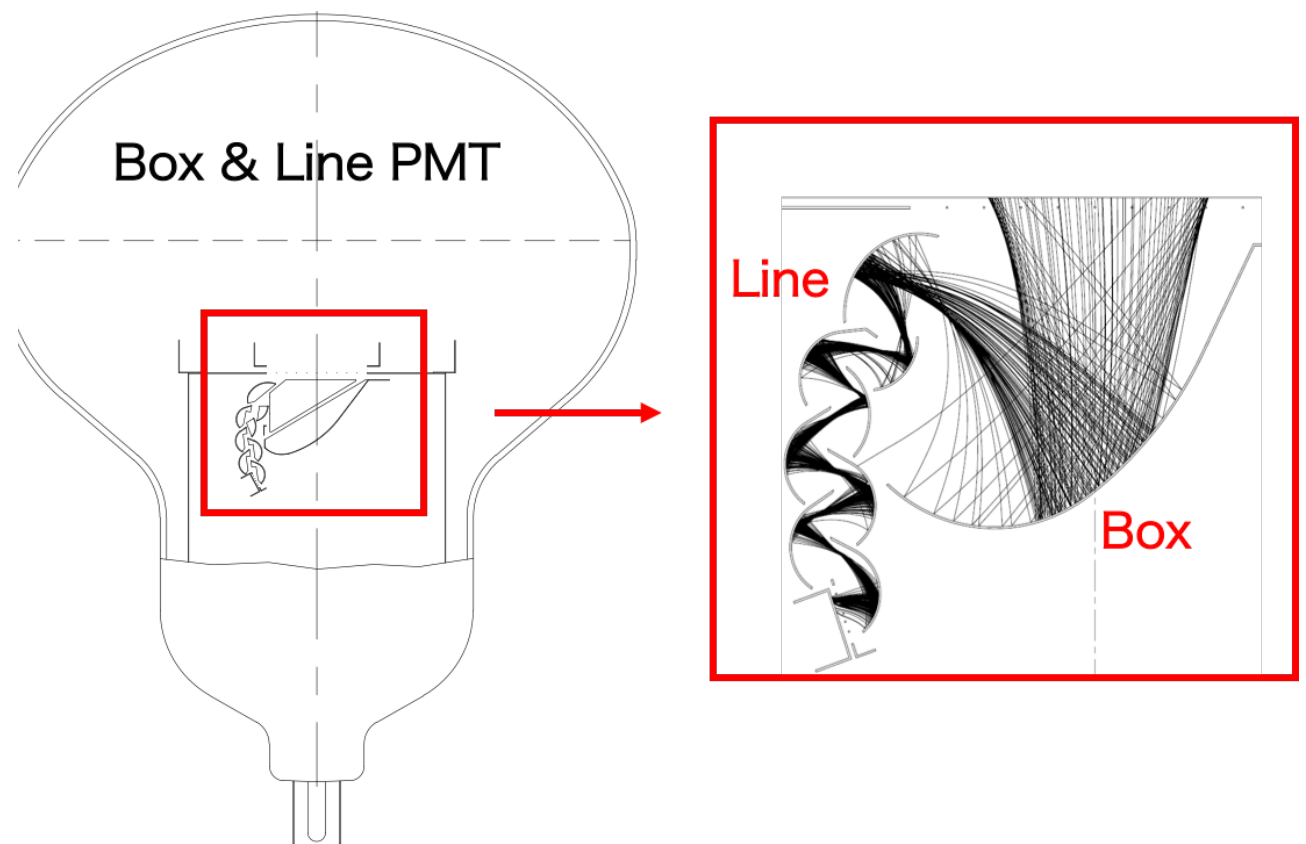
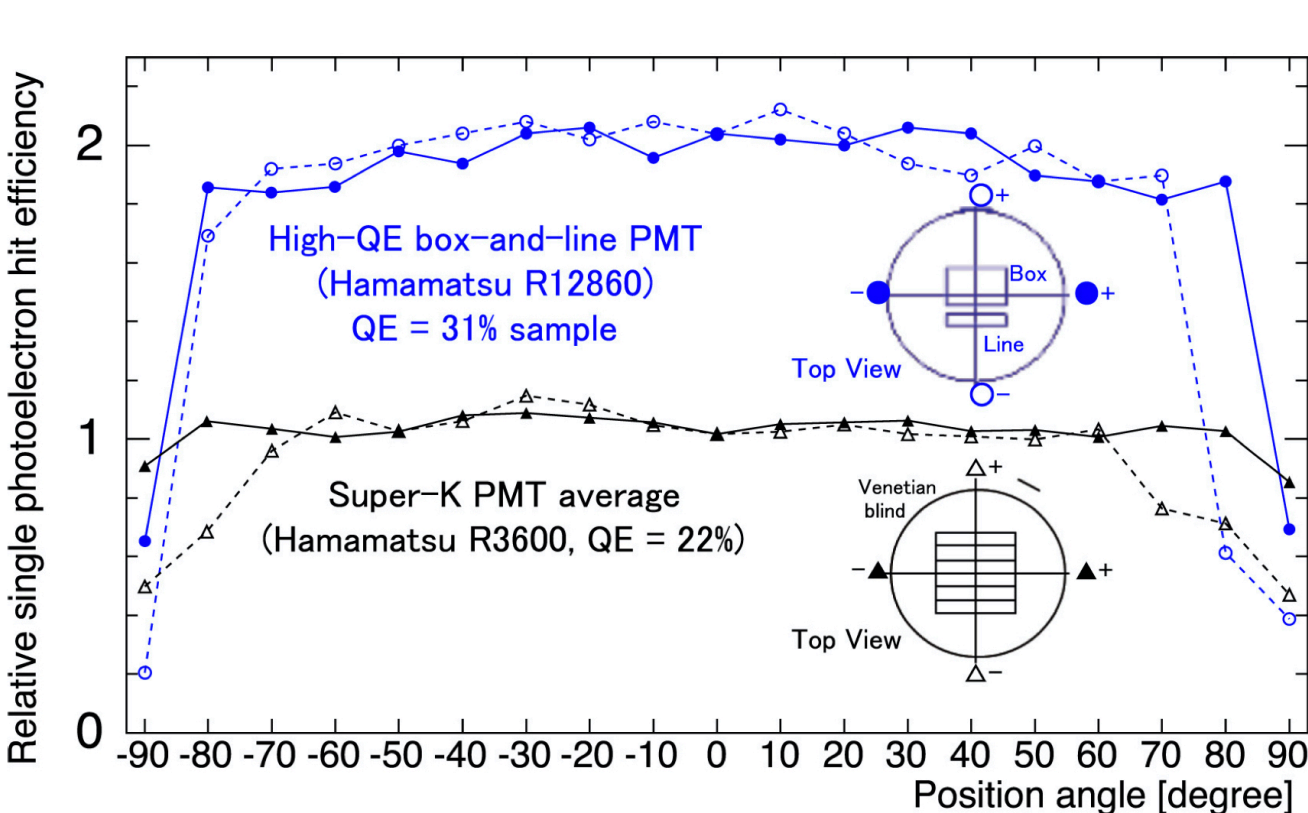
Summary

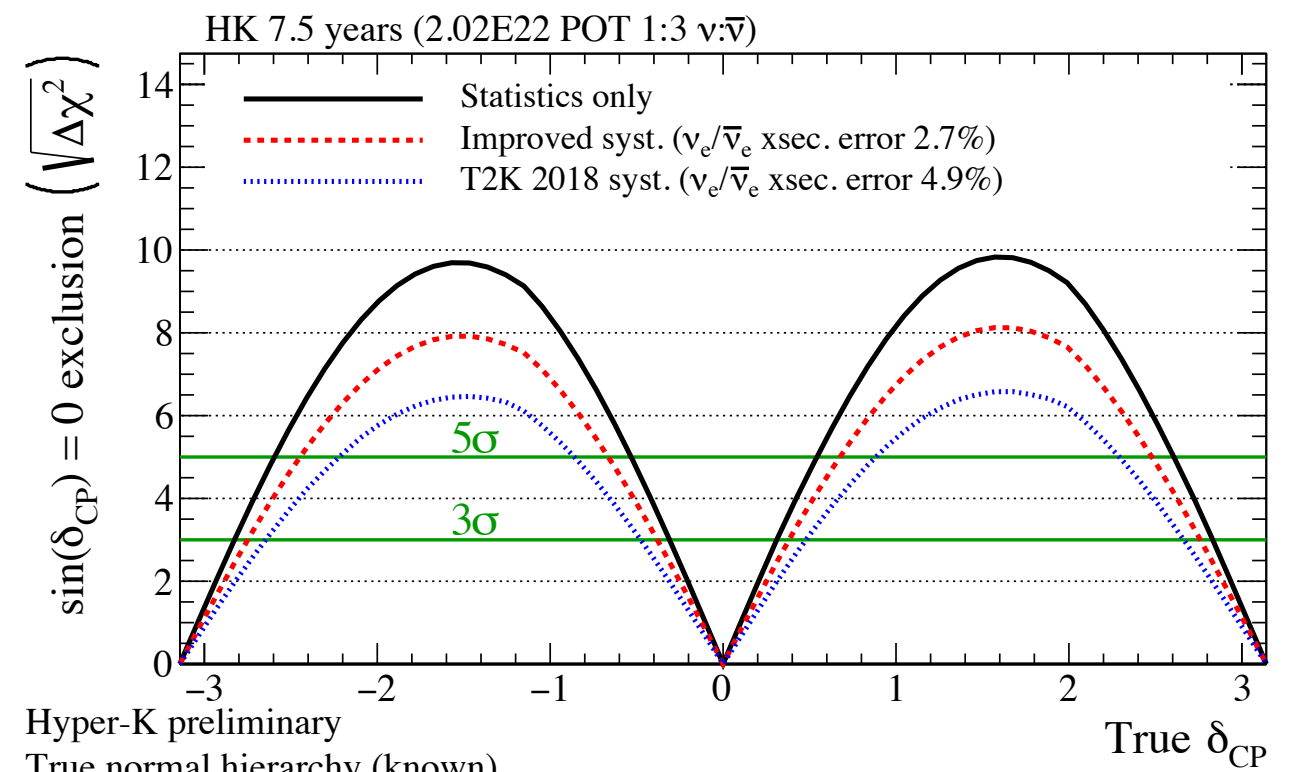
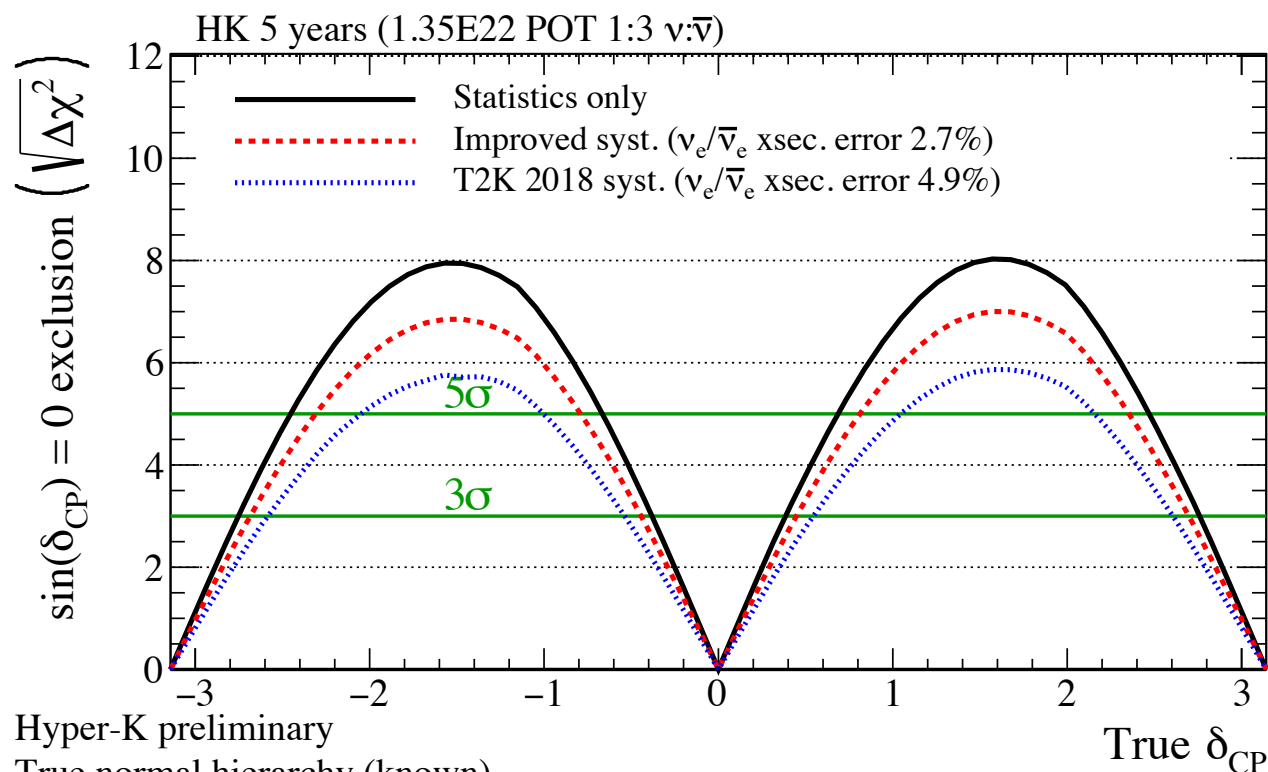
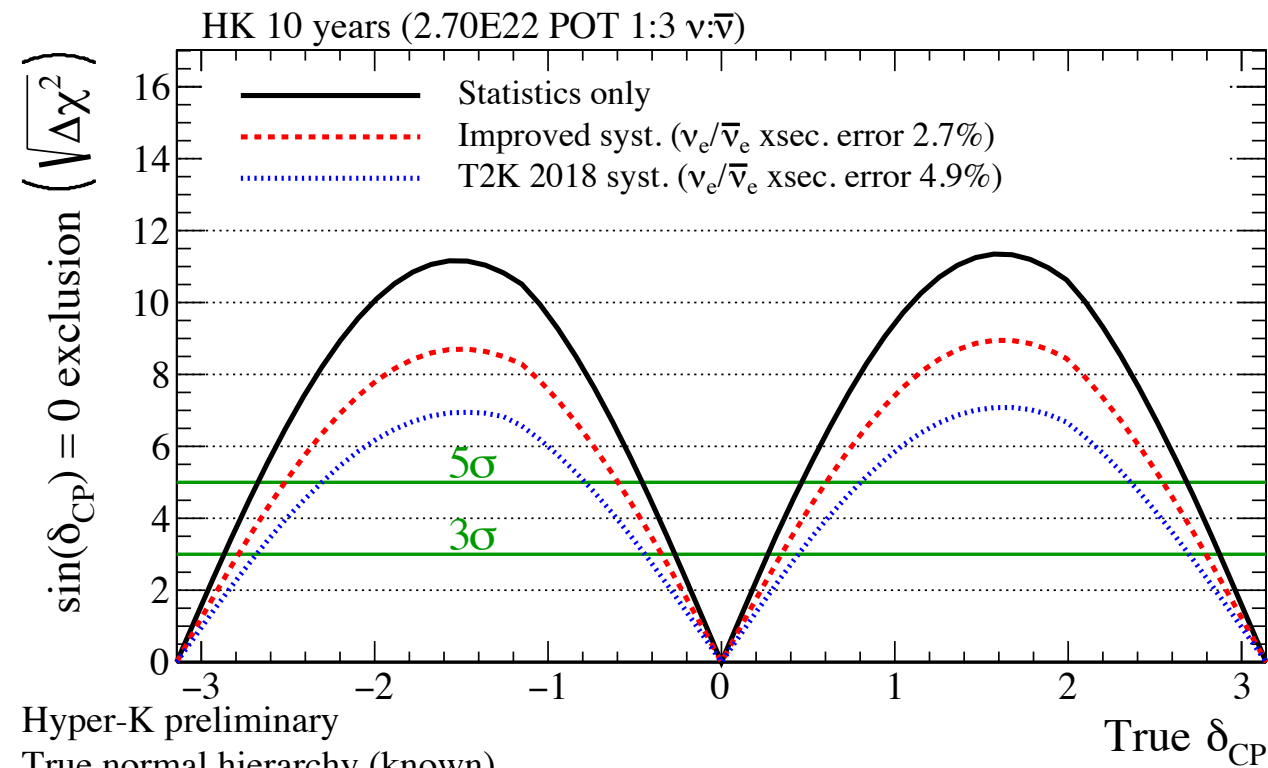
- HK, new water-Cherenkov detector is being constructed and the operation will start in 2028.
- Various important physics features including neutrino oscillation, nucleon decay, and neutrino astronomy will be explored.
- HK is expected to have sensitivity to conclude various physics questions within ~ 10 years of operation.
 - δ_{CP} and mass hierarchy in neutrino oscillation.
 - $O(10^{34})$ years of proton lifetime
 - D/N asymmetry and upturn in solar neutrinos.
 - Existence of SRN neutrinos.
- HK has the ability to observe the SN neutrinos if the SN burst occurs in our galaxy.
- Preparation of each component is ongoing.

Back up

New 50cm PMT

- ▶ In HK, Box&Line PMTs will be employed as the 50cm ID PMTs.
- ▶ The dynode structure is modified and larger quantum and correction efficiency is realized.
The detection efficiency is $\sim$ twice as large as the SK PMTs.
- ▶ The timing and energy resolution are also improved and they are about 2 times better than SK PMTs.





Sensitivity to $\sin^2\theta_{23}$

