PHYSICS PROSPECTS FOR THE HYPER-KAMIOKANDE EXPERIMENT

NATALY OSPINA

On behalf of the Hyper-Kamiokande Collaboration

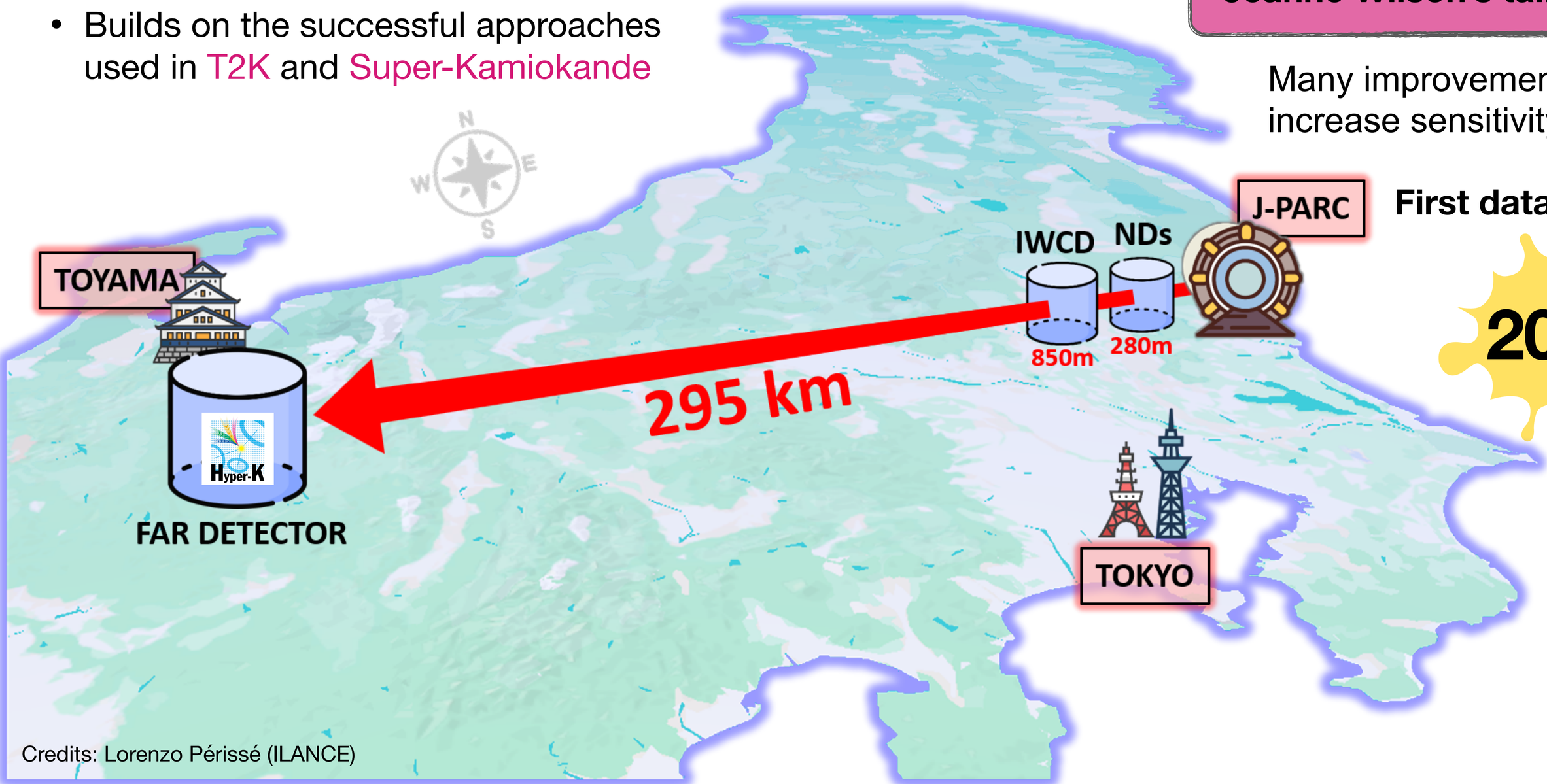
INFN - Sezione di Bari

The next-generation Water Cherenkov experiment in Japan

- Builds on the successful approaches used in T2K and Super-Kamiokande

Jeanne Wilson's talk!

Many improvements to increase sensitivity!

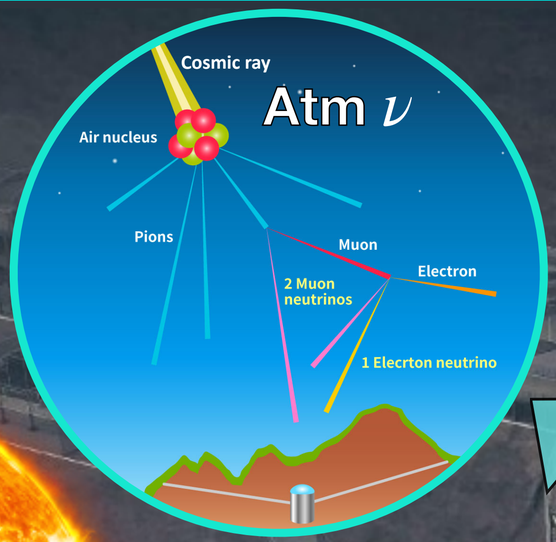


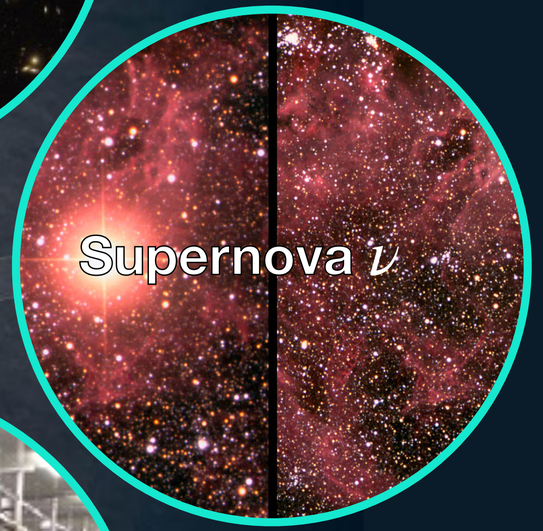
First data:

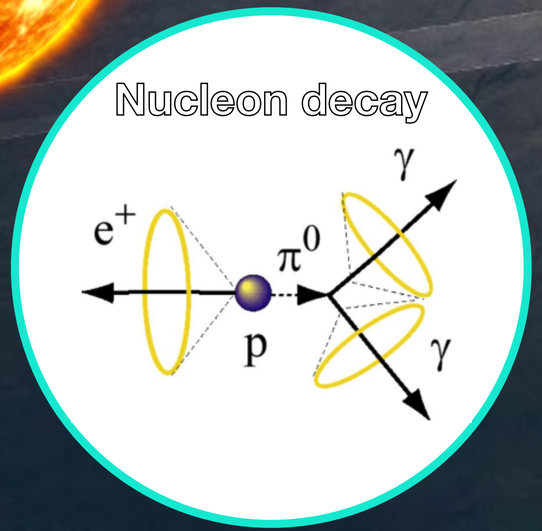
2028

Credits: Lorenzo Périssé (ILANCE)

PHYSICS TARGETS







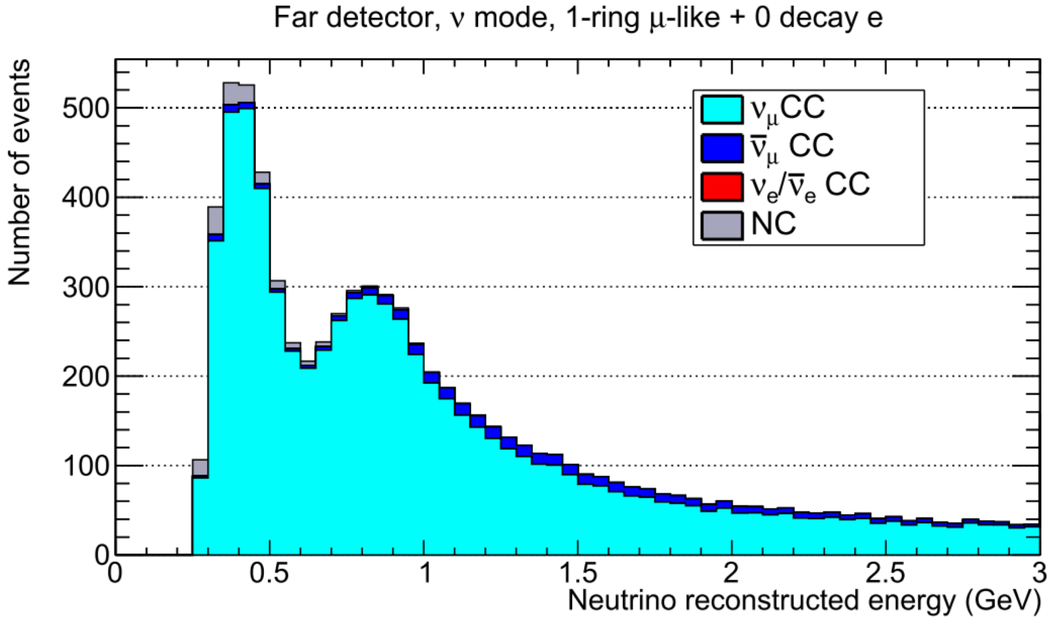
NEUTRINO OSCILLATION: EVENT RATES

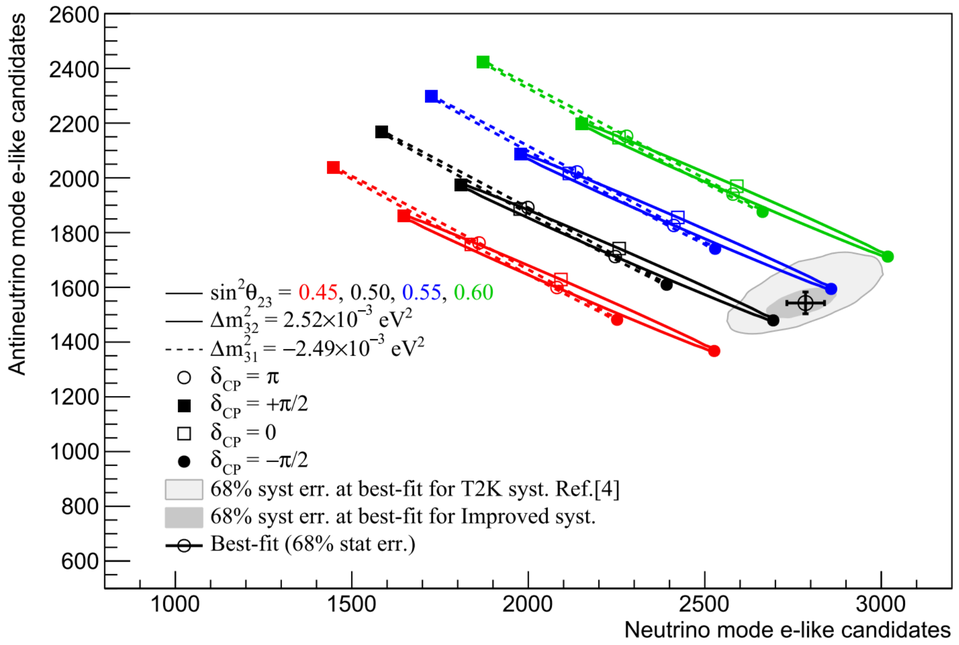
✓ Expecting ~(25–100)× larger event samples compared with T2K

→ each δ_{CP} value predicts a distinguishable pair of ν and $\bar{\nu}$ event counts

Candidate events

	ν_μ disapp.	ν_e app.
ν-mode	8845	2474
$\bar{\nu}$-mode	12027	1542





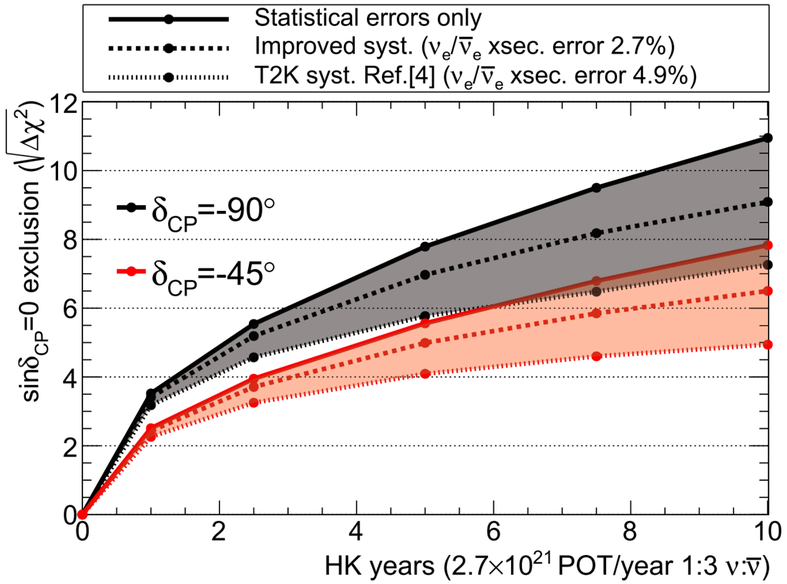
✓ Sensitivity projections assume 10 years, 27×10^{21} POT

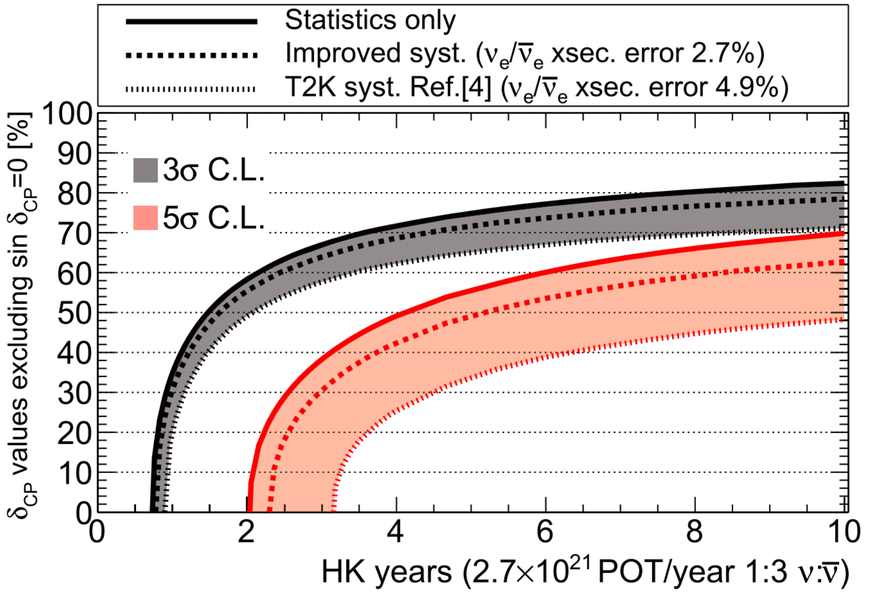
✓ Ratio of 1:3 for ν : $\bar{\nu}$ modes

Eur. Phys. J. C 86, 170 (2026)

NEUTRINO OSCILLATION: δ_{CP} SENSITIVITY

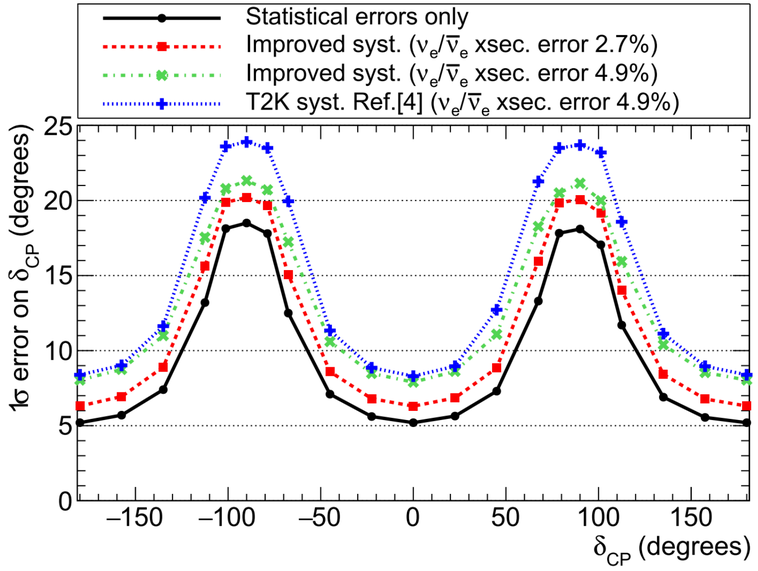
- ✓ δ_{CP} is currently unconstrained; measurements imply broad range of permissible values





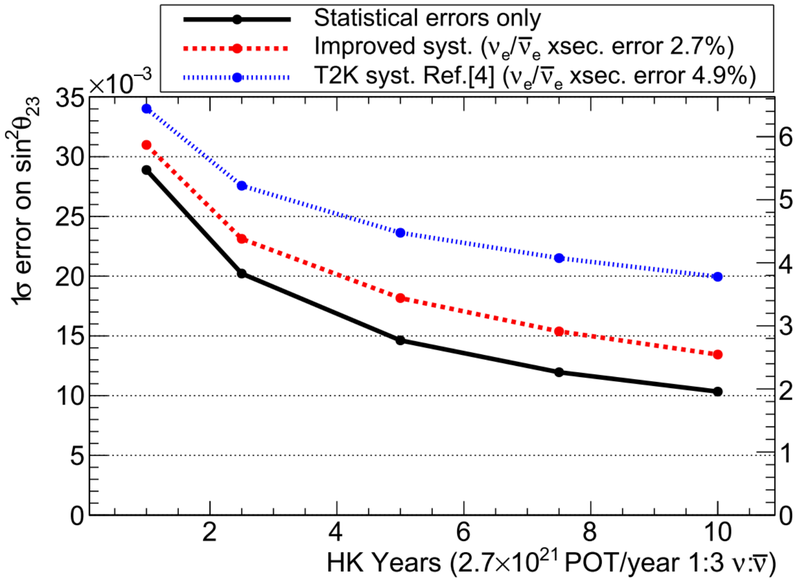
Eur. Phys. J. C 86, 170 (2026)

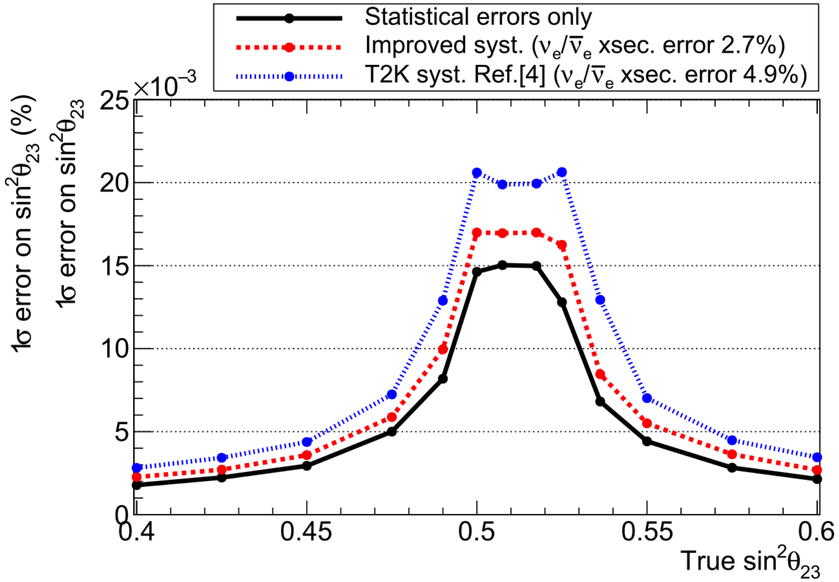
- ✓ 5σ in first 3 years for $\delta_{CP} \sim -90^{\circ}$
- ✓ After 10 years
  - 5σ CPV for 60% of the parameter space
  - 1σ error uncertainty: 20° for $\delta_{CP} \sim -90^{\circ}$, 6° for $\delta_{CP} \sim 0$
- ✓ Controlling $\nu_e/\bar{\nu}_e$ cross-section systematic uncertainties is vital
  - Aim to reduce ~5% to ~3%

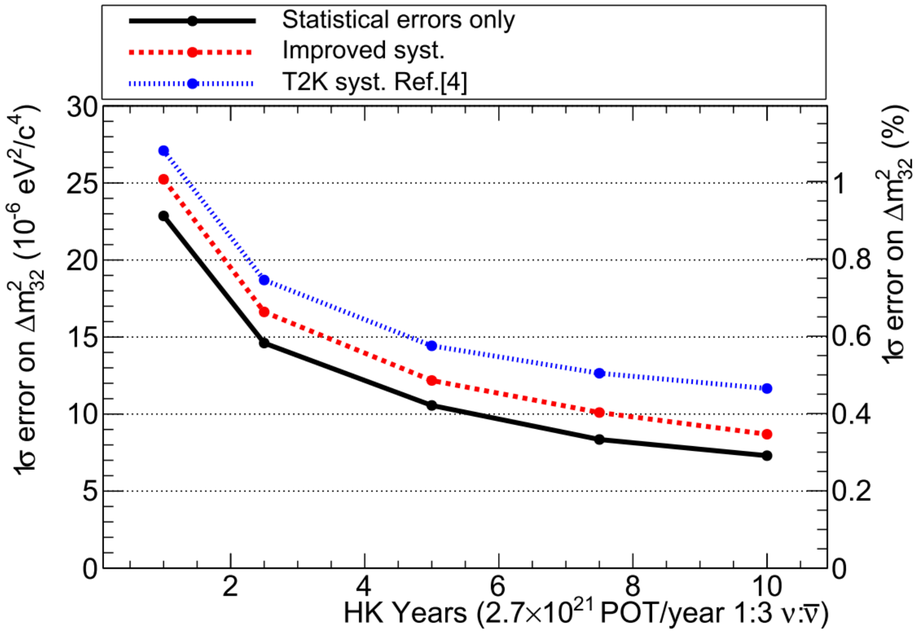


NEUTRINO OSCILLATION: θ_{23} AND Δm^2_{32} SENSITIVITY

✓ θ_{23} octant ambiguity unresolved; Δm^2_{32} currently known to ~1%





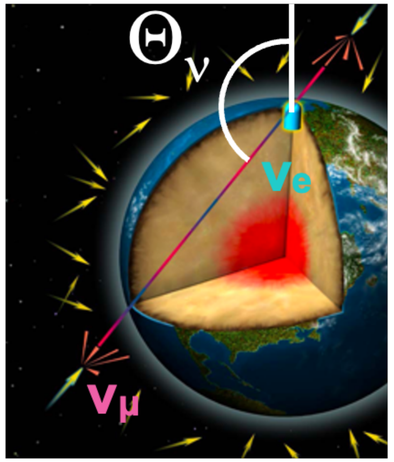


Eur. Phys. J. C 86, 170 (2026)

✓ After 10 years: wrong octant excluded at 3σ for $\sin^2\theta_{23} \in [0,\ 0.47] \cup [0.55,\ 1]$

✓ Δm^2_{32} precision reaches ~0.3 – 0.5%

NEUTRINO OSCILLATION: ATMOSPHERIC NEUTRINOS



✓ Neutrino mass ordering remains unknown

Normal: $m_1 < m_2 < m_3$

Inverted: $m_3 < m_1 < m_2$

✓ ~80 events per day (all flavour of ν & $\bar{\nu}$)

✓ Wide range of neutrino energy (sub-GeV – TeV) & baseline (10km – 10,000 km) provide an excellent opportunity to study various properties of ν

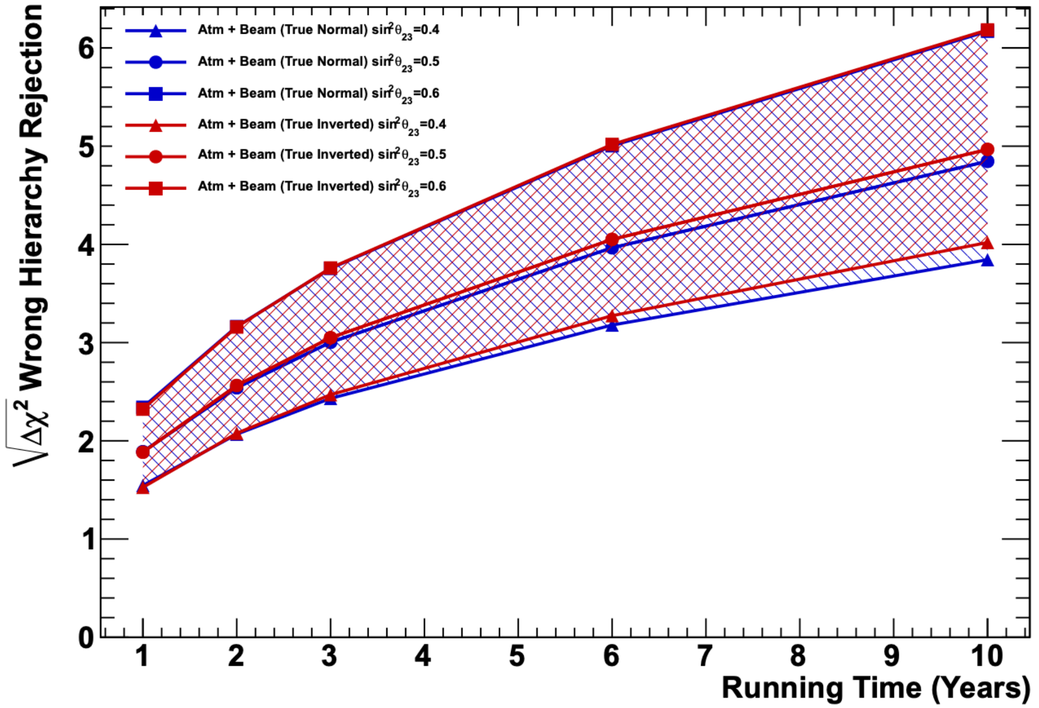
✓ Neutrinos crossing the Earth acquire matter effects which vary between orderings and θ_{23} octants

✓ Combining atmospheric data with the beam sample drives Hyper-K's ordering sensitivity

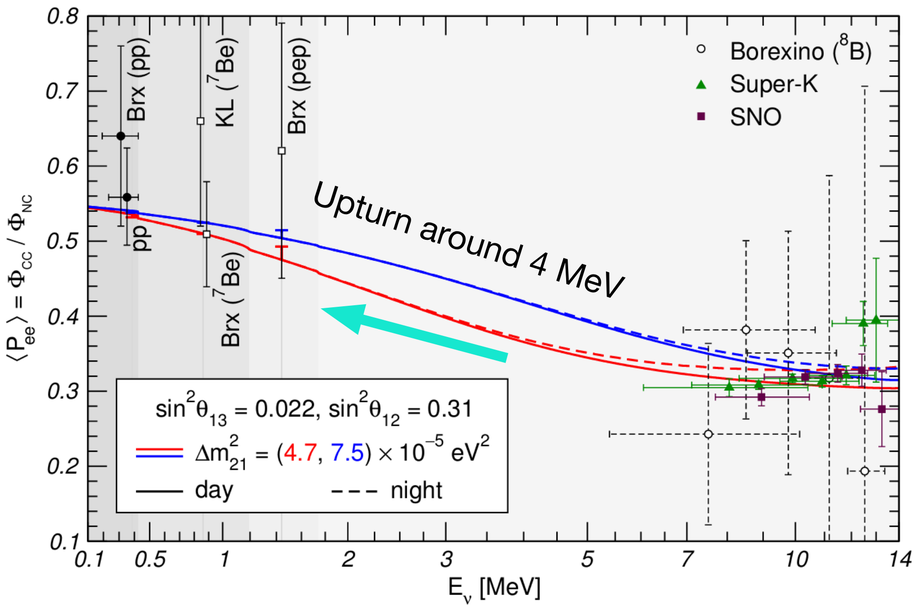
✓ Expect wrong hierarchy rejection after 10 years to:

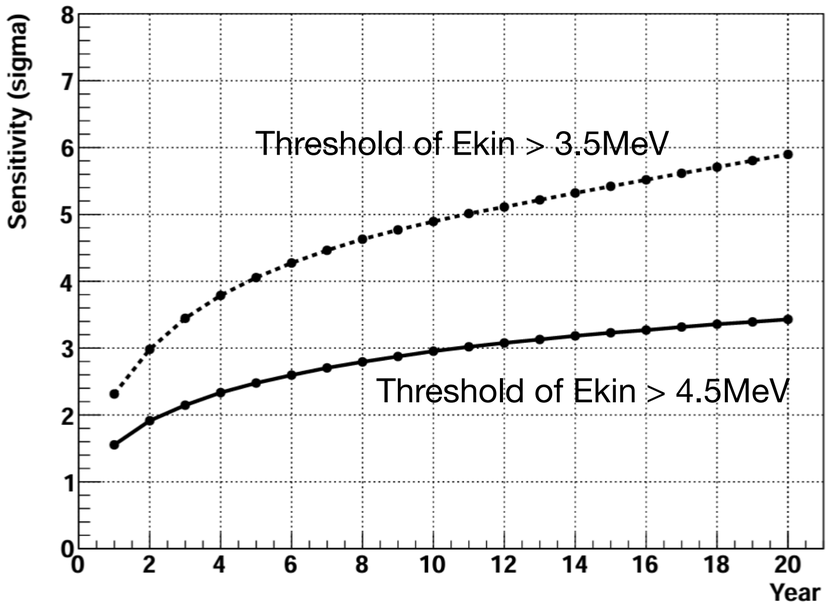
$3.8\sigma(6.2\sigma)$ for $\sin^2\theta_{23} = 0.4(0.6)$

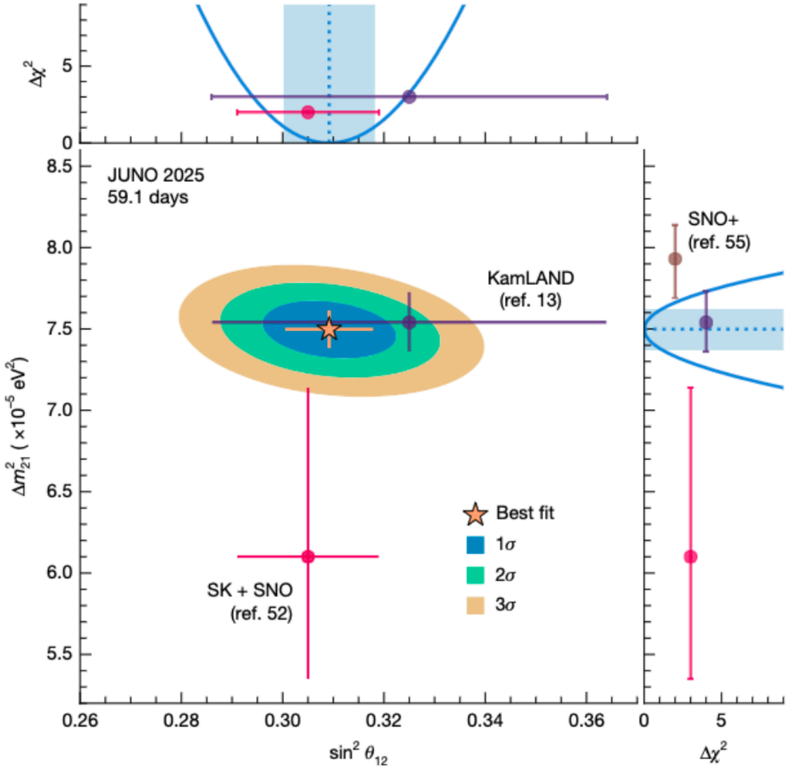
Hyper-K Design Report, arXiv:1805.04163 (2018)



- ✓ Expecting ~5 ^{8}B ν interactions/hr
- ✓ Search for solar 'upturn' in ν_e survival probability due to MSW transition → > 3σ in 10 years
- ✓ Can probe the tension between solar and reactor determinations of Δm^2_{21} seen at JUNO





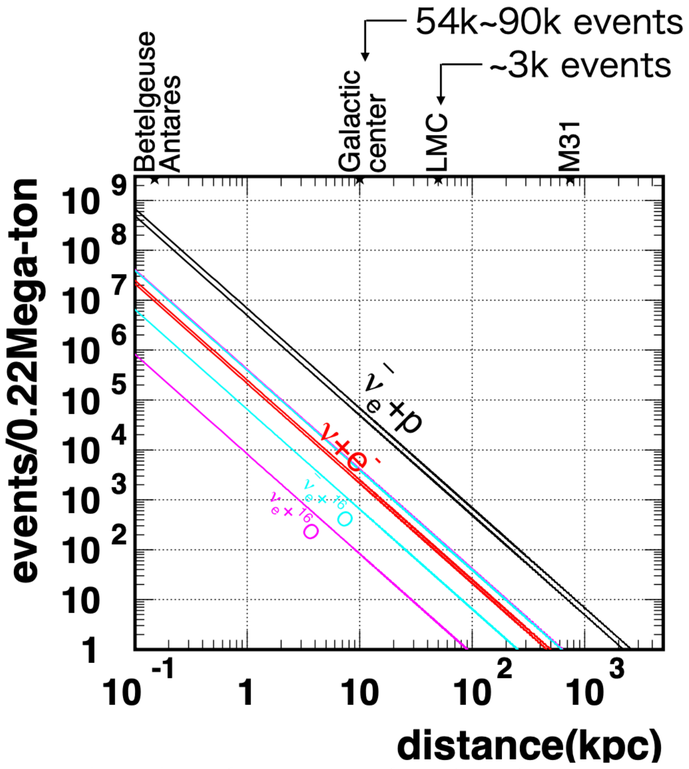


M. Maltoni et al., Eur. Phys. J. A52, 87 (2016)

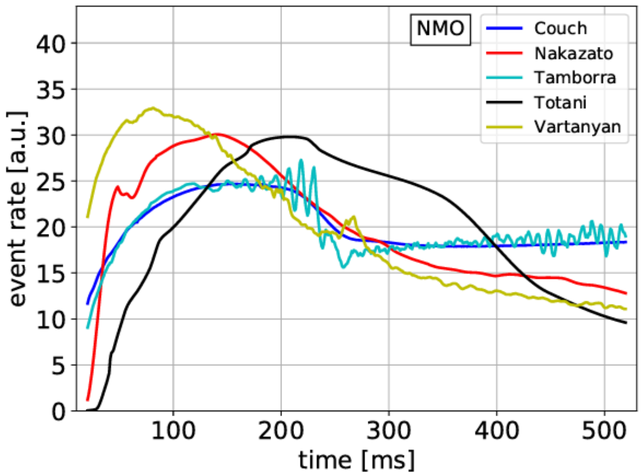
Hyper-K Design Report, arXiv:1805.04163 (2018)

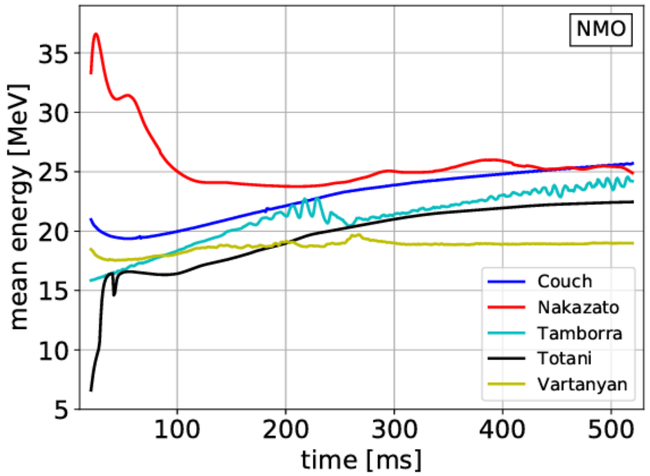
Nature 654, 343–348 (2026)

- ✓ Detectable @ 770 kpc (= M31)
- ✓ High statistics @ 10 kpc (= galactic center); 70,000 events
  - Sensitive to explosion mechanism & BH/NS formation, providing model disc. power
  - Alert with ~1° pointing accuracy for multi-messenger observation



Expected number of events as a function of supernova distance





Number of Events Expected in Hyper-Kamiokande

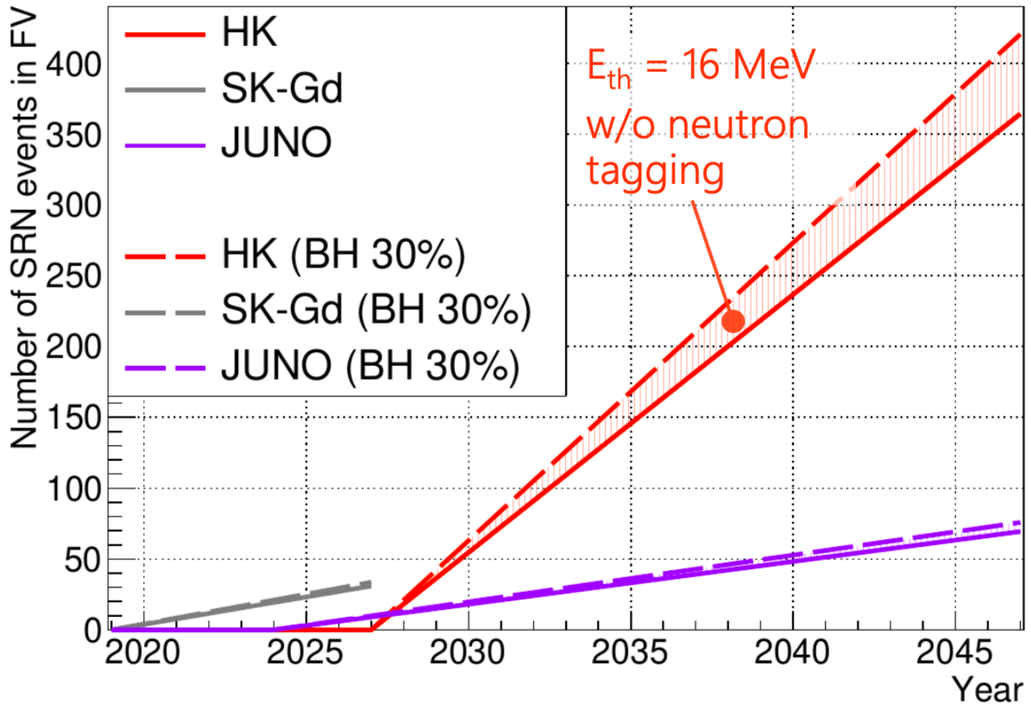
K. Abe et.al., ApJ. 916:15 (2021)

Model	Normal Mass Ordering			Inverted Mass Ordering		
	$N_{10\ \mathrm{kpc}}$	d_{100}	d_{300}	$N_{10\ \mathrm{kpc}}$	d_{100}	d_{300}
Totani	20021	141 kpc	82 kpc	22717	151 kpc	87 kpc
Nakazato	17978	134 kpc	77 kpc	16005	127 kpc	73 kpc
Couch	27539	166 kpc	96 kpc	24983	158 kpc	91 kpc
Vartanyan	10372	102 kpc	59 kpc	9400	97 kpc	56 kpc
Tamborra	25025	158 kpc	91 kpc	20274	142 kpc	82 kpc

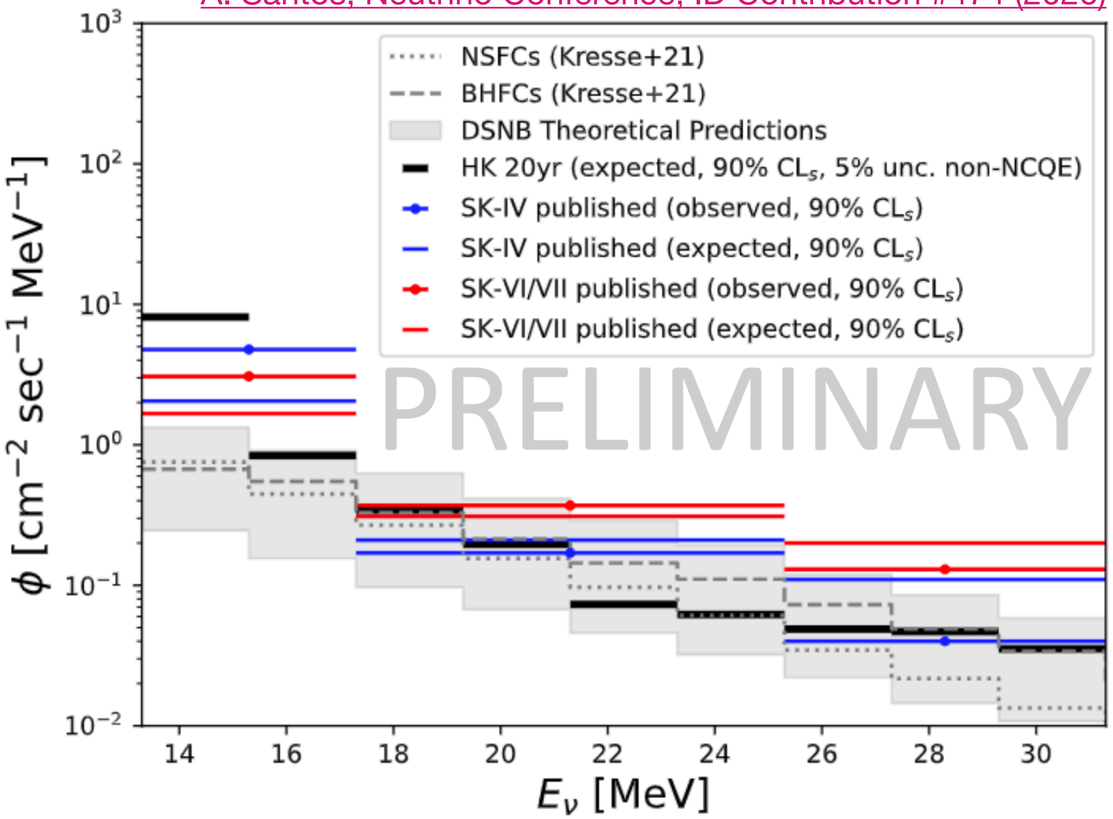
Statistical studies with 5 different SN models

ASTROPHYSICS: DIFFUSE SUPERNOVA NEUTRINO BACKGROUND

Hyper-K Design Report, arXiv:1805.04163 (2018)



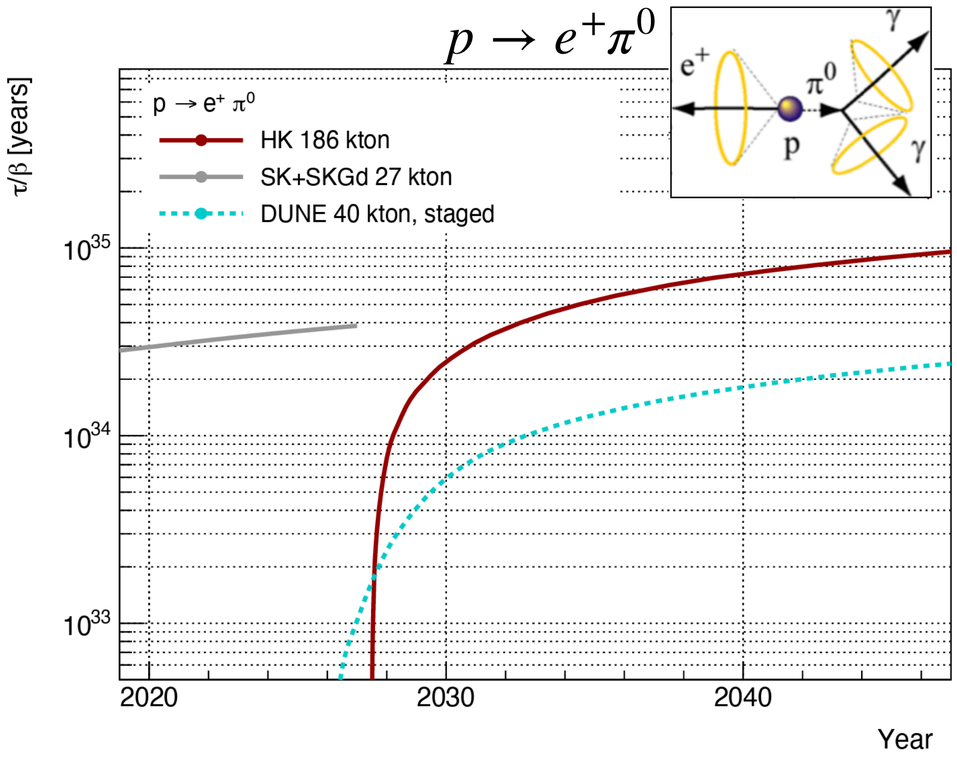
A. Santos, Neutrino Conference, ID Contribution #474 (2026)

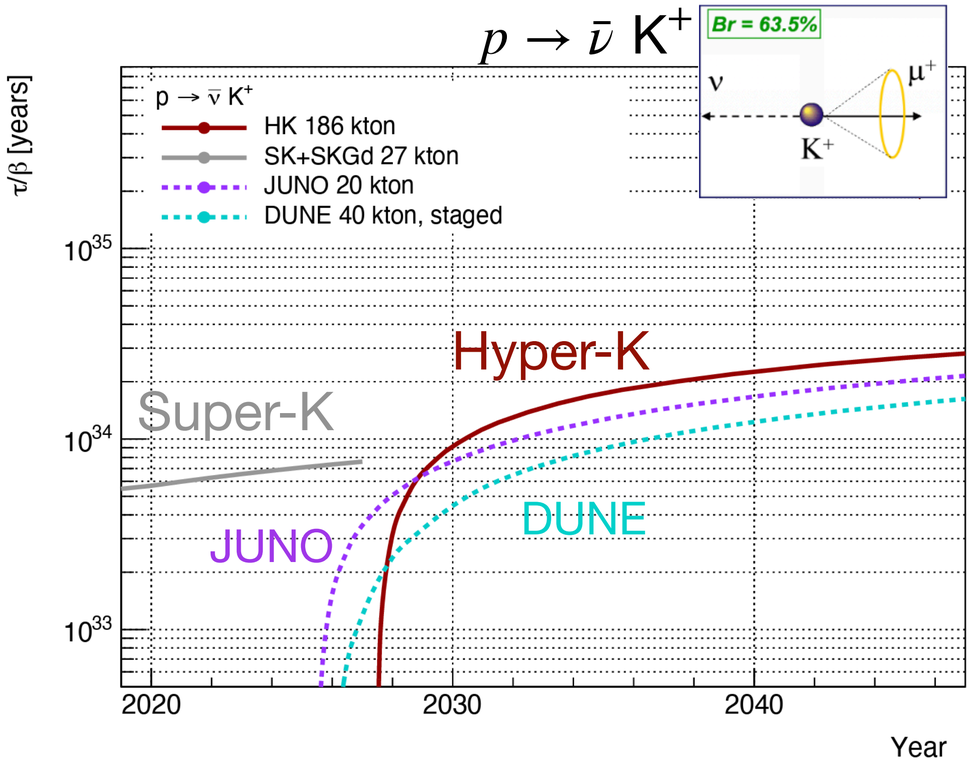


- ✓ Expect a DSNB flux of ~ a few $\bar{\nu}_e/\mathrm{cm}^2/\mathrm{s}$
- ✓ Super-K reports a first indication at 2.6σ [K. Abe et.al., ApJ. 1005:101 (2026)]
- ✓ Hyper-K could turn this indication into a measurable spectrum

  → expects $\mathcal{O}(10^2)$ relic ν after 10 years

- ✓ Nucleon decay is predicted by several Grand Unified Theories





- ✓ 10 years of Hyper-K probes $\tau_p \sim 10^{35}$ yr
- ✓ Will play the world-leading role:
  - $p \to e^+\pi^0$: $\sim 6 \times 10^{34}$ years in 10 years
  - $p \to \bar{\nu}\ K^+$: $\sim 2 \times 10^{34}$ years in 10 years

K. Abe et al, arXiv:2506.16641 (2025)

SUMMARY

- Hyper-Kamiokande will use its unprecedented event statistics and improved control of systematic uncertainties to perform precision measurements of neutrino oscillations
- After 10 years, Hyper-K is expected to establish CP violation at 5σ for approximately 60% of the possible δ_{CP} values and reach a precision of about 0.3 – 0.5% on Δm^2_{23}
- Combining beam and atmospheric neutrinos will provide sensitivity to the θ_{23} octant and allow the wrong mass ordering to be rejected with a significance of 3.8 – 6.2σ, depending on the true value of $\sin^2\theta_{23}$
- Hyper-K will provide a broad astrophysics program, including the solar neutrino spectral upturn, approximately 70,000 events from a supernova at 10 kpc, and $\mathcal{O}(10^2)$ DSNB events after 10 years
- Hyper-K will perform world leading searches for proton decay, probing partial lifetimes up to $\sim 6 \times 10^{34}$ years for $p \to e^+\pi^0$ and 2×10^{34} years for $p \to \bar{\nu}\ \mathrm{K}^+$ after 10 years

Hyper-K is not only a bigger Super-K: it is a precision oscillation experiment and a multi-purpose neutrino observatory!

Virtual tour at https://www-sk.icrr.u-tokyo.ac.jp/en/hk/virtual/