Non-Beam Physics at Hyper-Kamiokande

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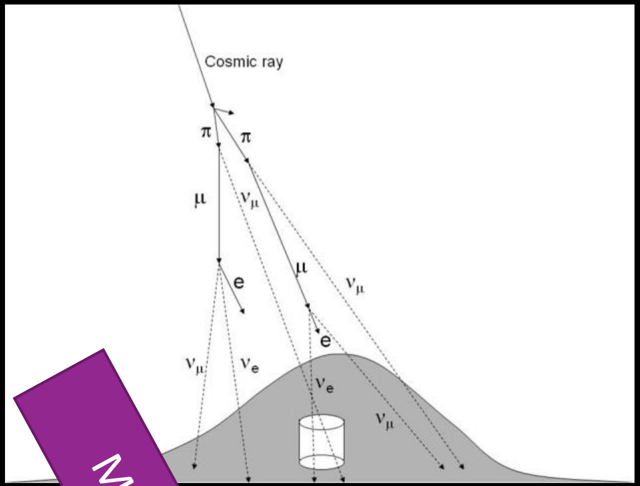
For the Hyper-Kamiokande Collaboration

Hyper-Kamiokande

9–13 June 2025
University of Sussex, Brighton, UK
WiN 25

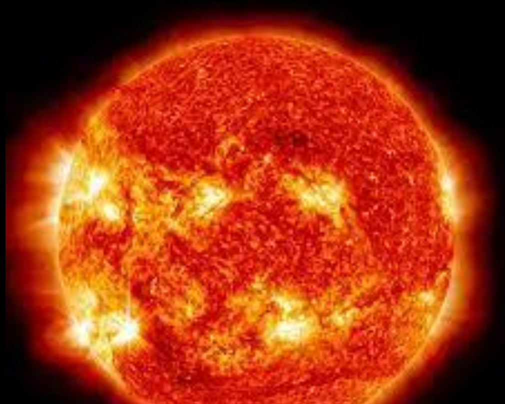
KING'S College LONDON

The Hyper-Kamiokande Project



Atmospheric neutrinos: $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$

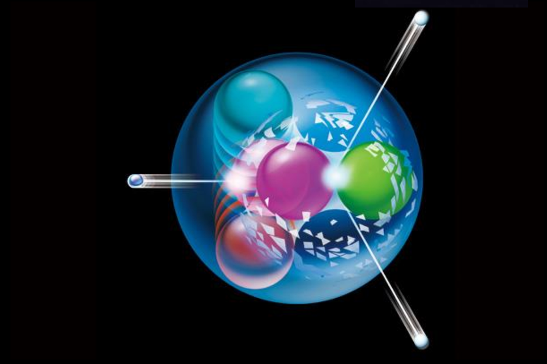
High Energy Neutrinos



Solar neutrinos, ν_e

Supernova bursts

Diffuse Supernova Background Neutrinos

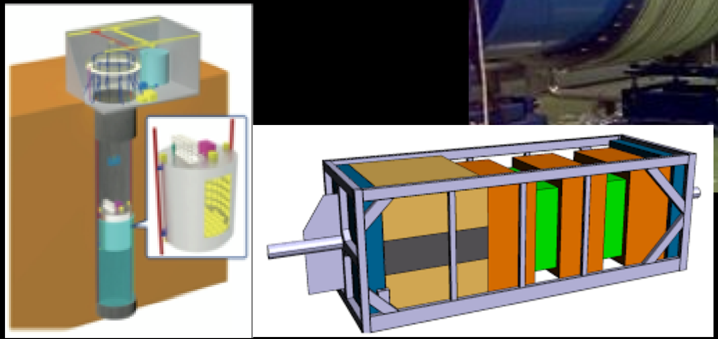


Proton Decay Search

Mass Ordering

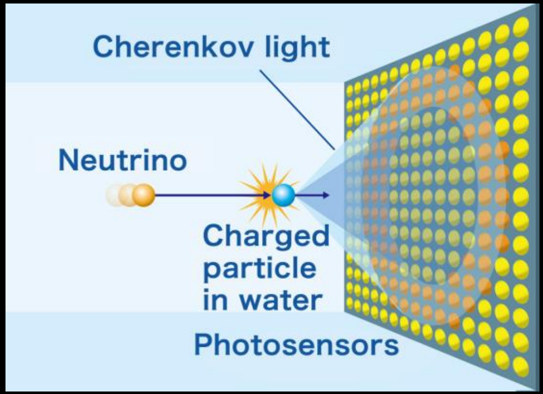
CP violation, oscillation parameters

J-PARC neutrino beam: $\nu_\mu, \bar{\nu}_\mu$



Near Detectors

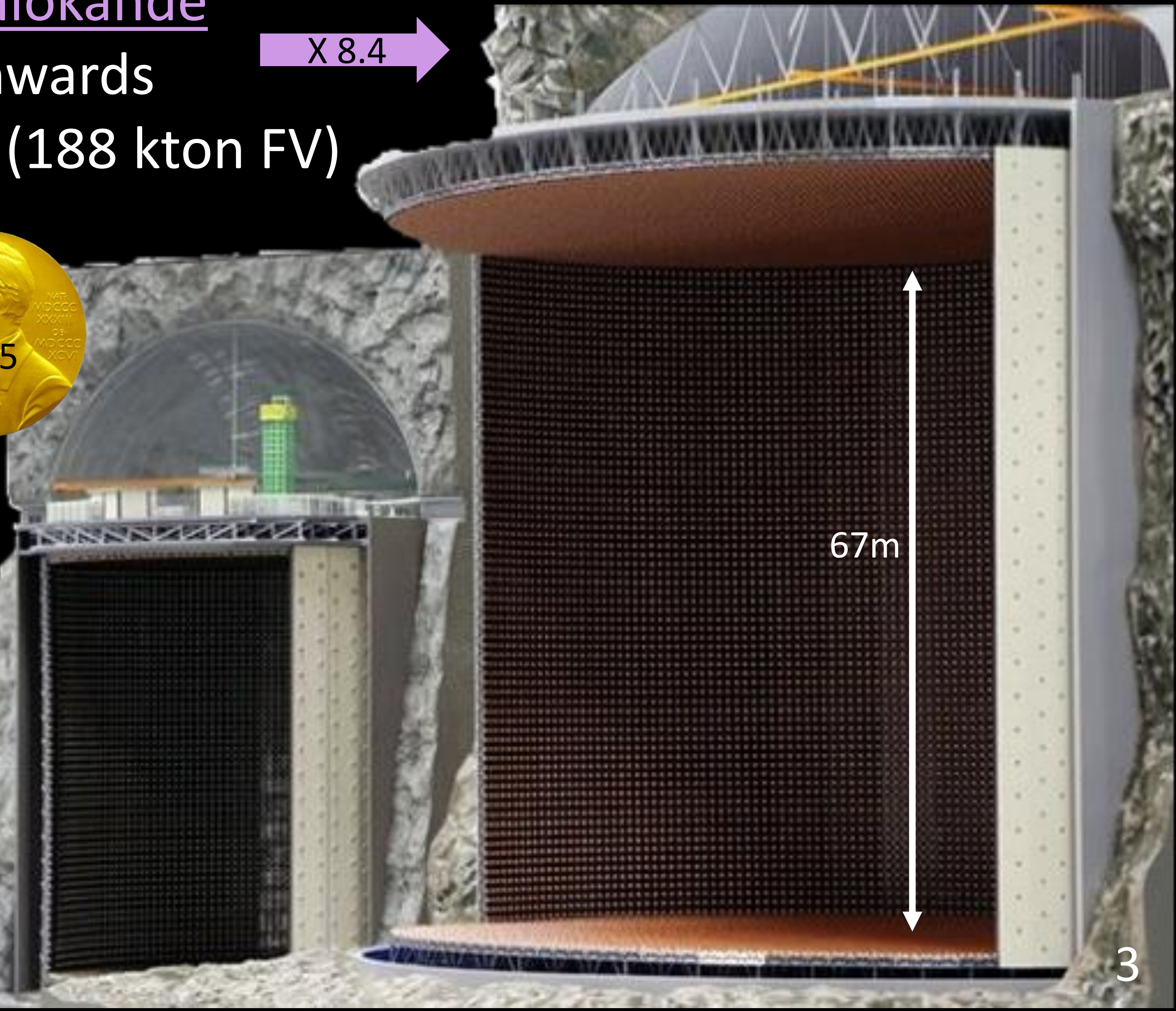
Kamioka Water Cherenkov Experiments



Hyper-Kamiokande

- ~2027 onwards
- 260 kton (188 kton FV)

X 8.4



Super-Kamiokande

X 20

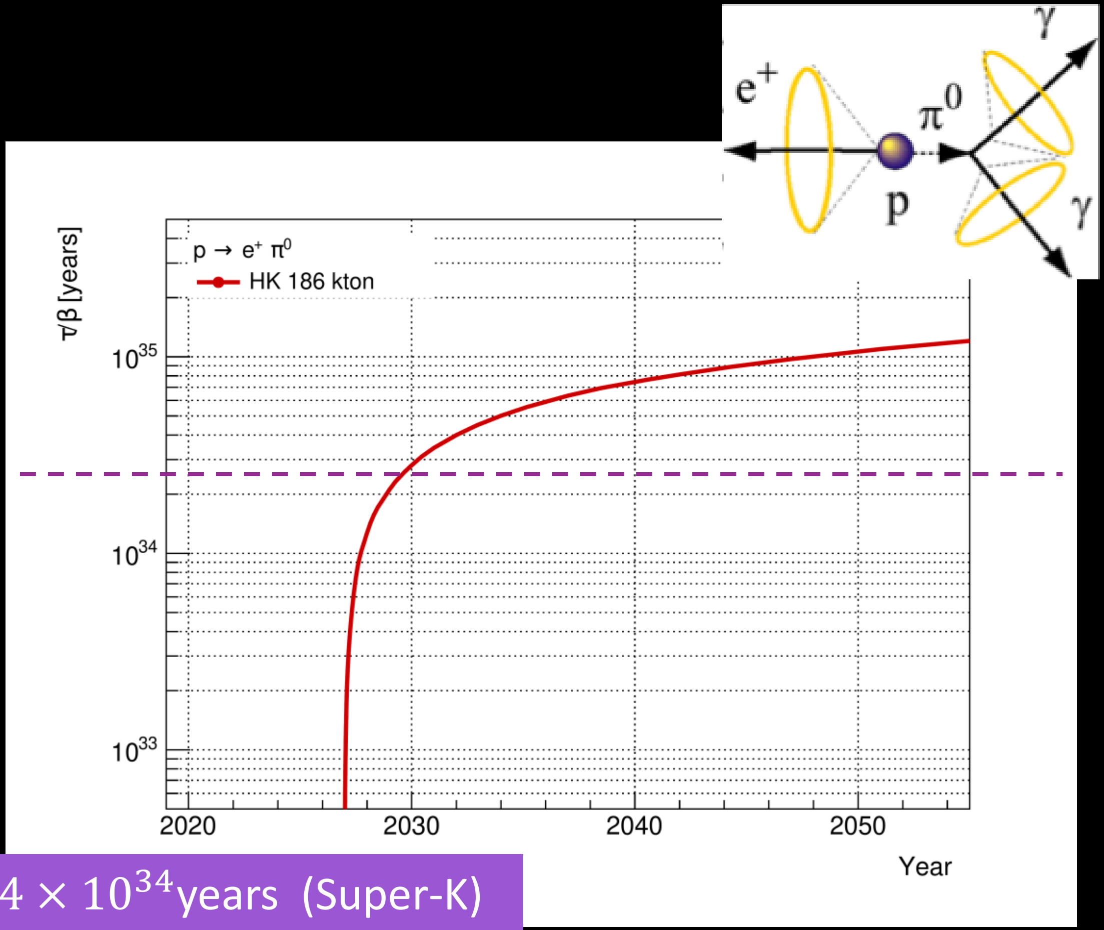
- 1996 onwards
- 50 kton (22.5 kton FV)

Kamiokande

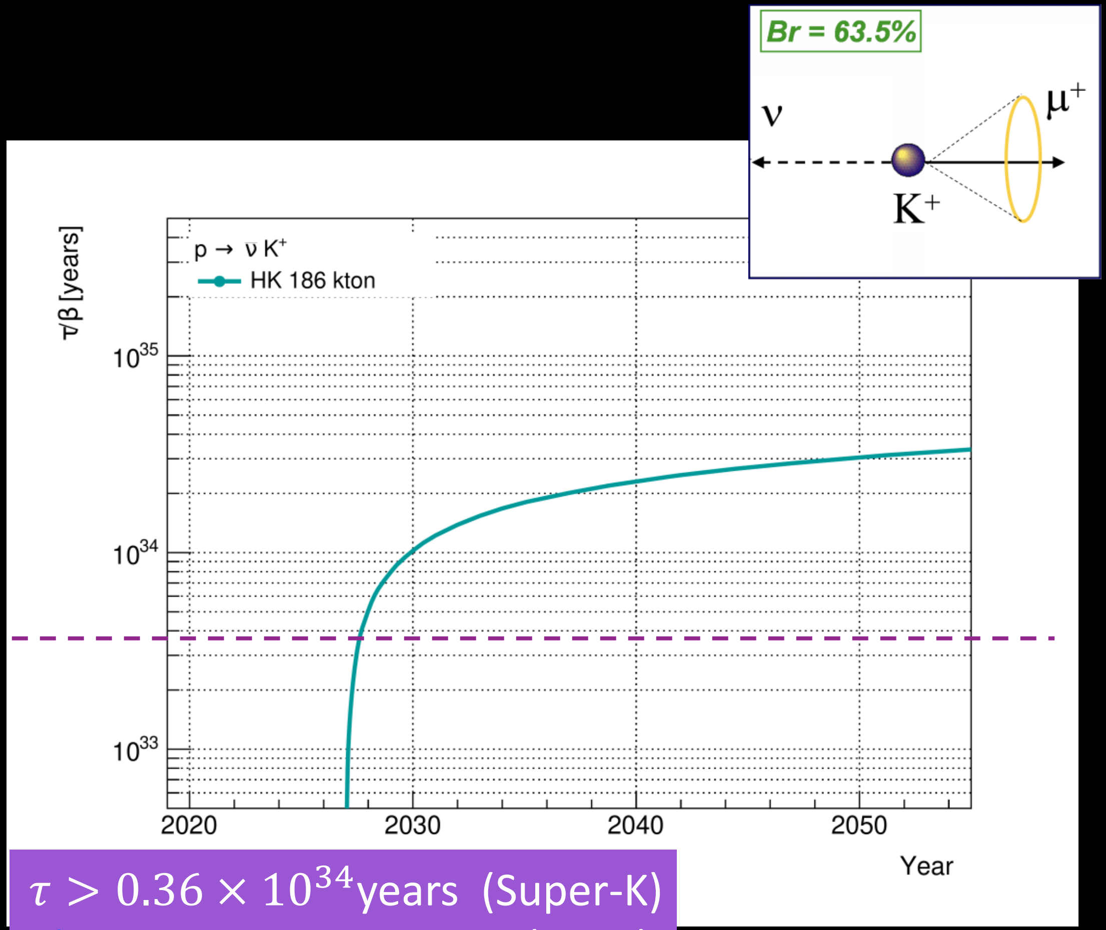
- 1983 – 1996
- 3 kton

Proton Decay

- Hyper-K far detector has many protons! (188kT = 8.4 × Super-K fiducial volume)
- Can extend proton decay search by an order of magnitude beyond current limits



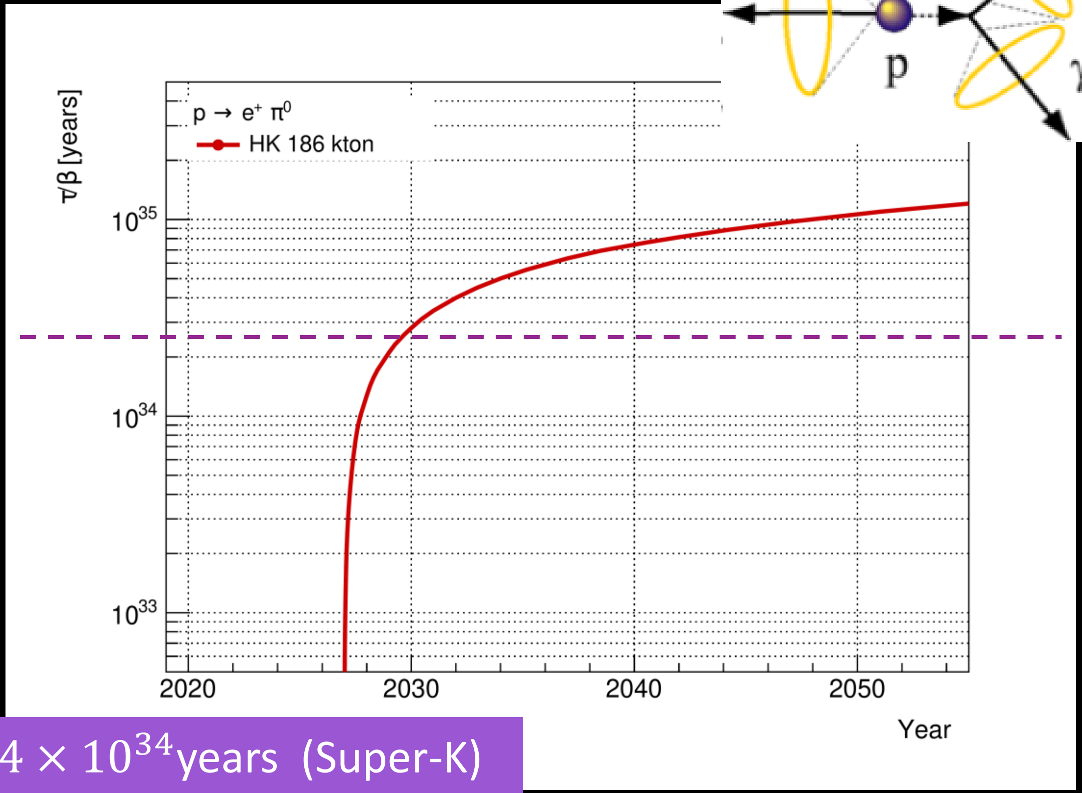
$\tau > 2.4 \times 10^{34}$years (Super-K)
Phys. Rev. D 102, 112011 (2020)

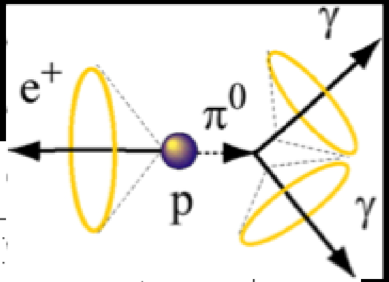


$\tau > 0.36 \times 10^{34}$years (Super-K)
Phys. Rev. D 106, 072003 (2022)

Proton Decay

- JUNO 10 year sensitivity = 9.6×10^{33} years Angel Abusleme et al 2023 Chinese Phys. C 47 113002
- DUNE 400 kt-yr sensitivity = 1.3×10^{34} years https://arxiv.org/pdf/2503.23291





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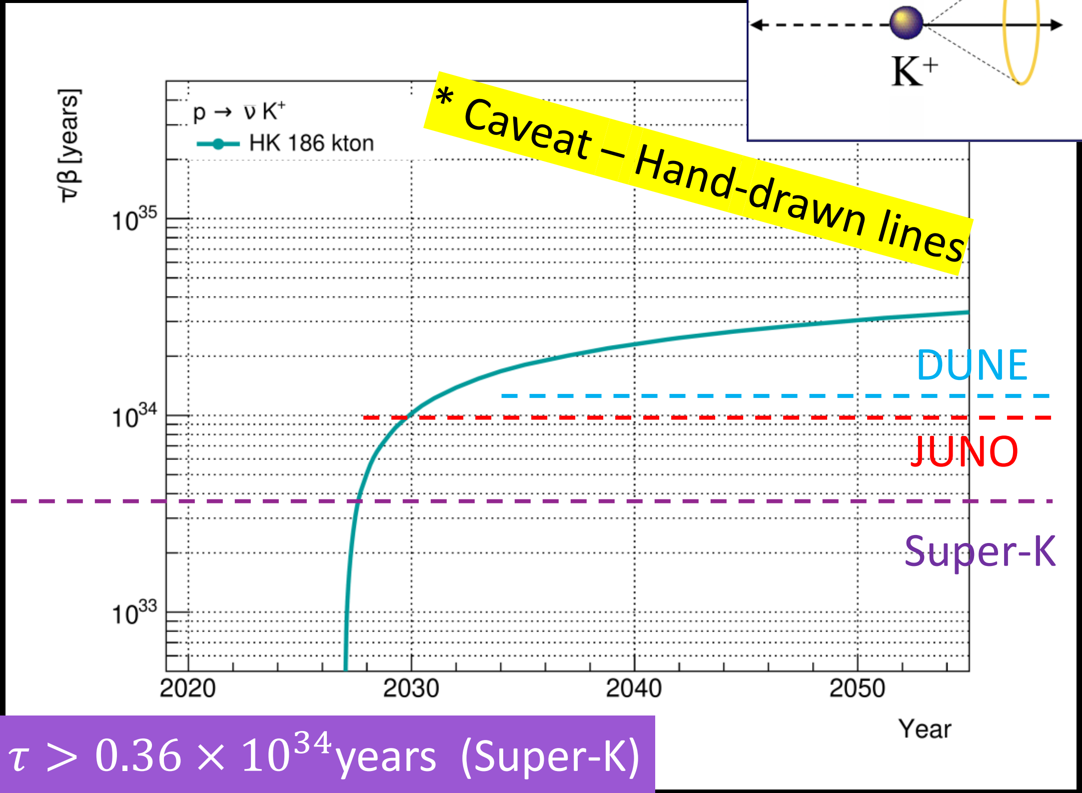

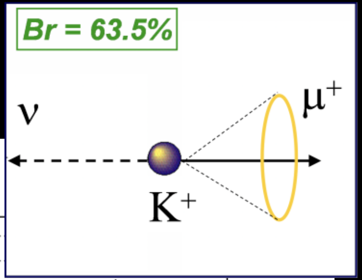

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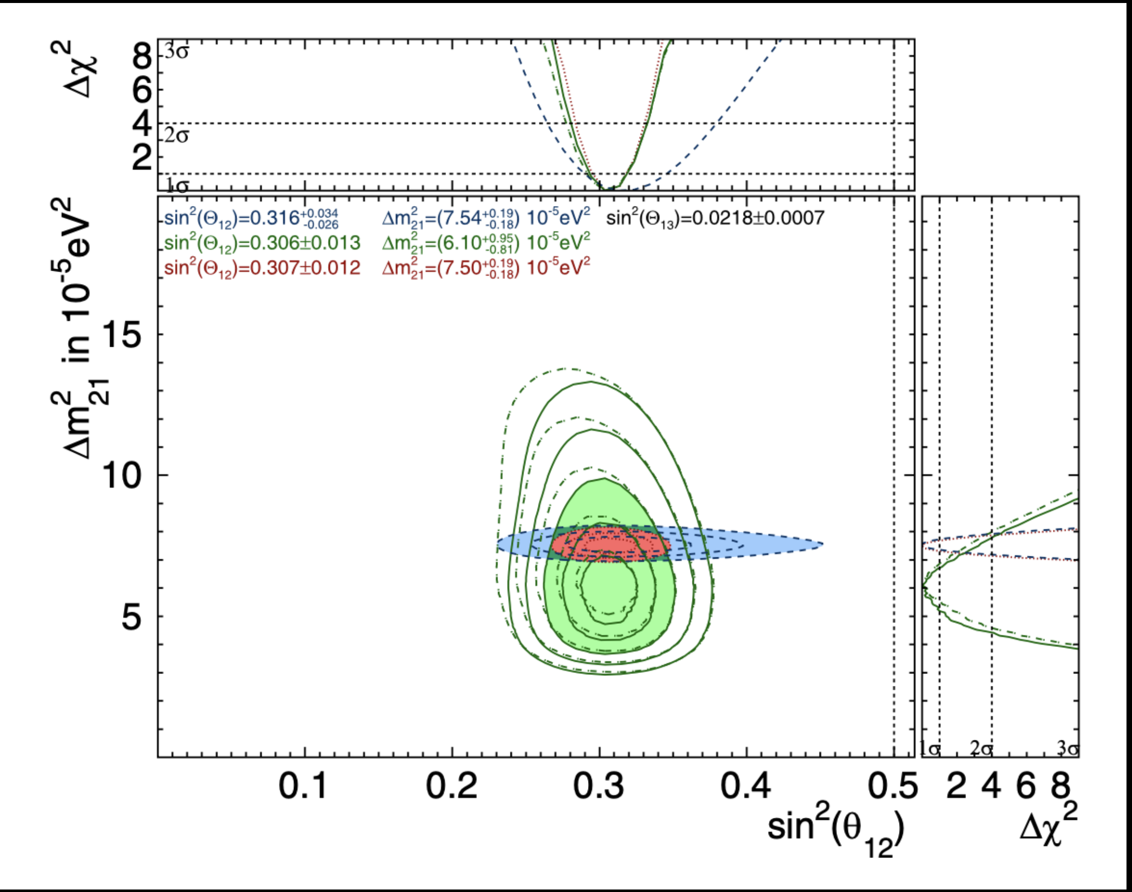
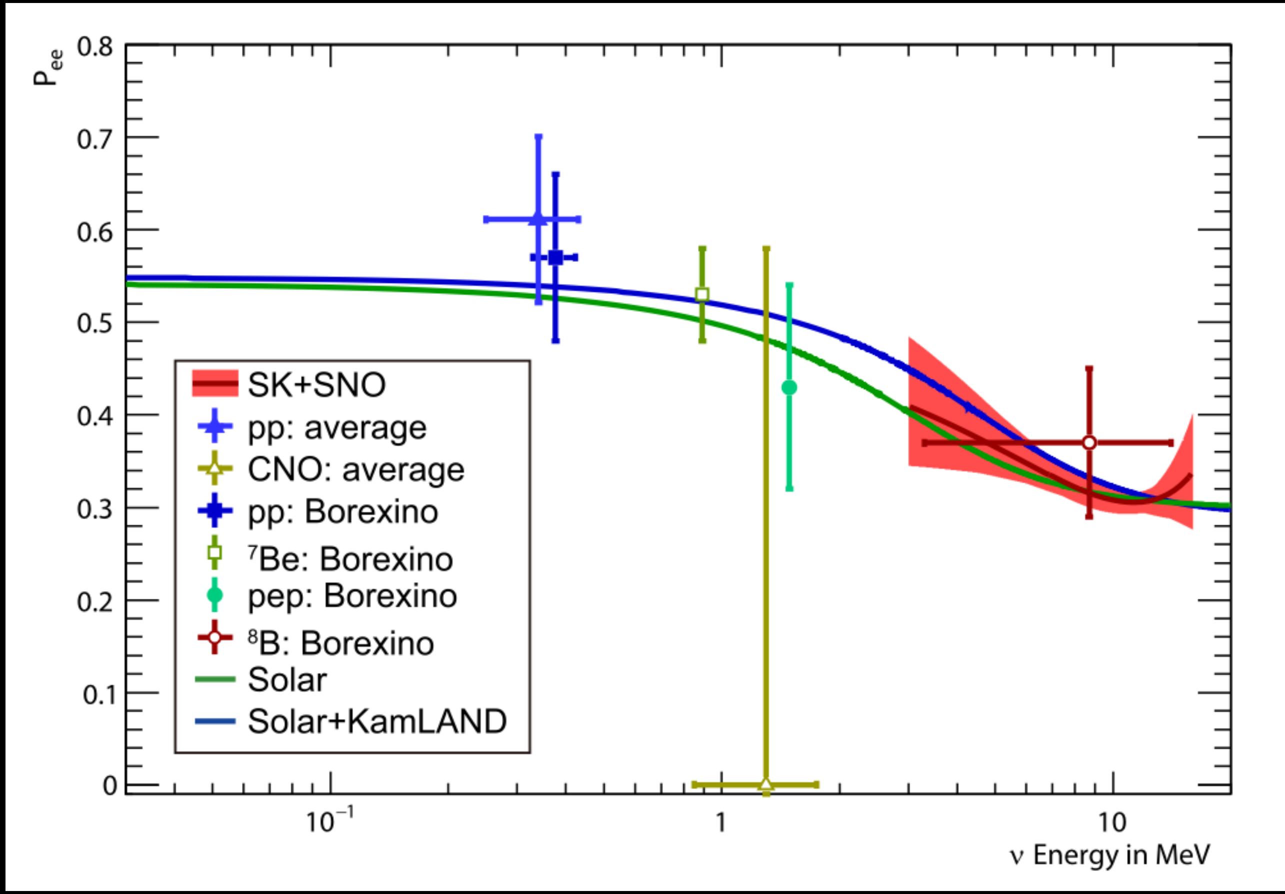
Phys. Rev. D 106, 072003 (2022)

Solar Neutrinos – current status

Super-Kamiokande - PHYSICAL REVIEW D 109, 092001 (2024)

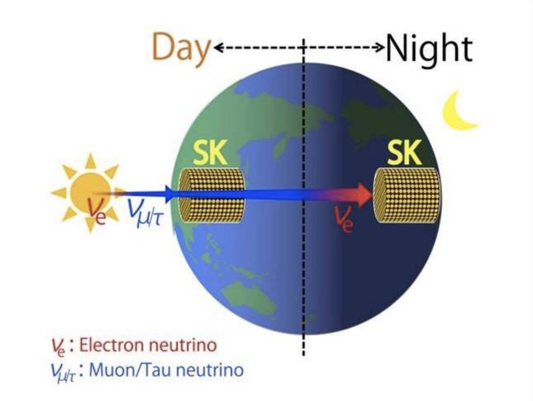




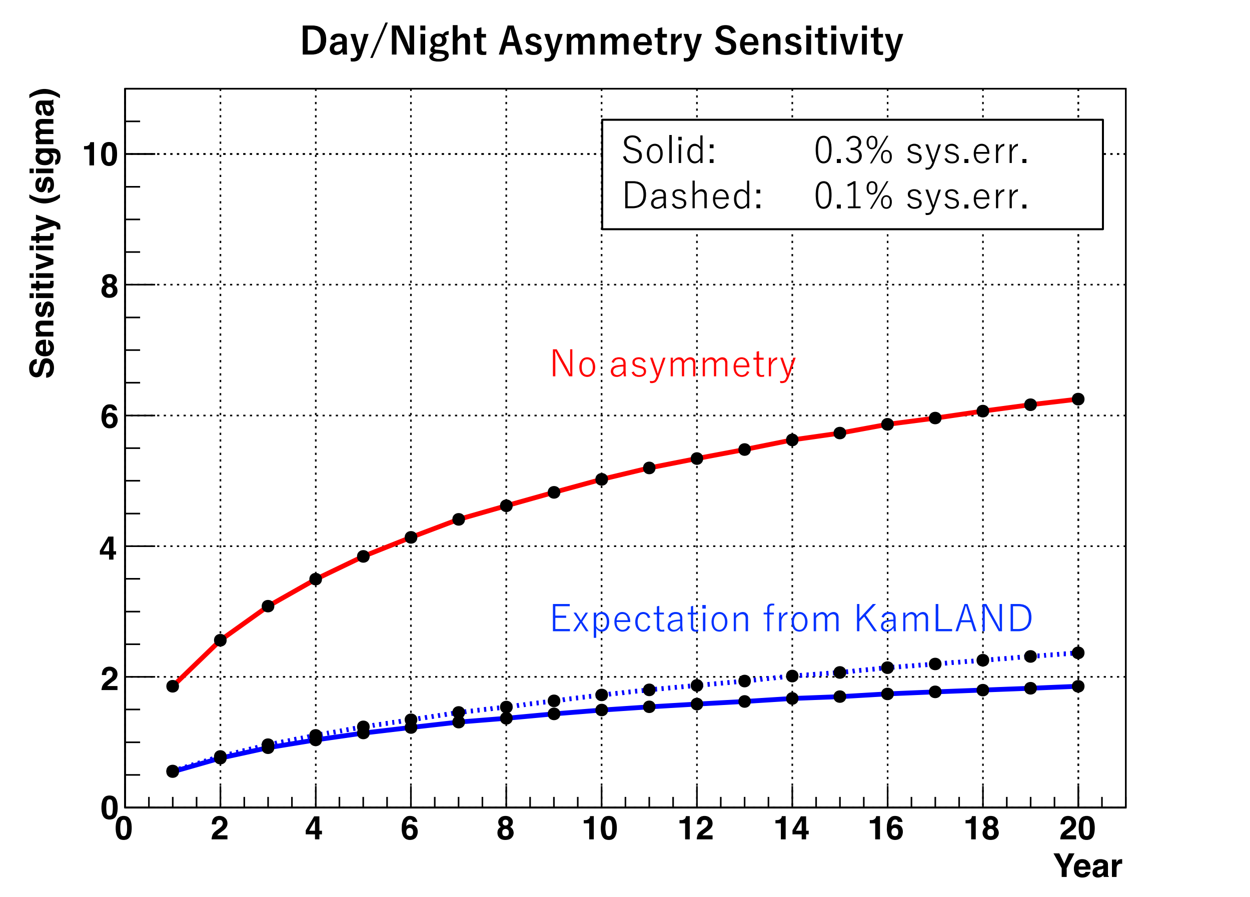
Global neutrino data (Green) prefer lower value of Δm^2_{21} than KamLAND reactor experiment ~1.5σ tension
Disagreement = CPT violation

Large Mixing Angle + MSW – expect upturn in solar ^{8}B spectrum at low energies
SK spectrum measurement favours the existence of an "upturn" by 1.2σ

Solar Neutrinos – Day/Night Asymmetry



- Larger survival probability expected at night due to MSW earth 'regeneration' effect
- Size of effect driven by 1-2 mixing parameters
- Super-K Day/Night asymmetry is higher than expected from the reactor constraint



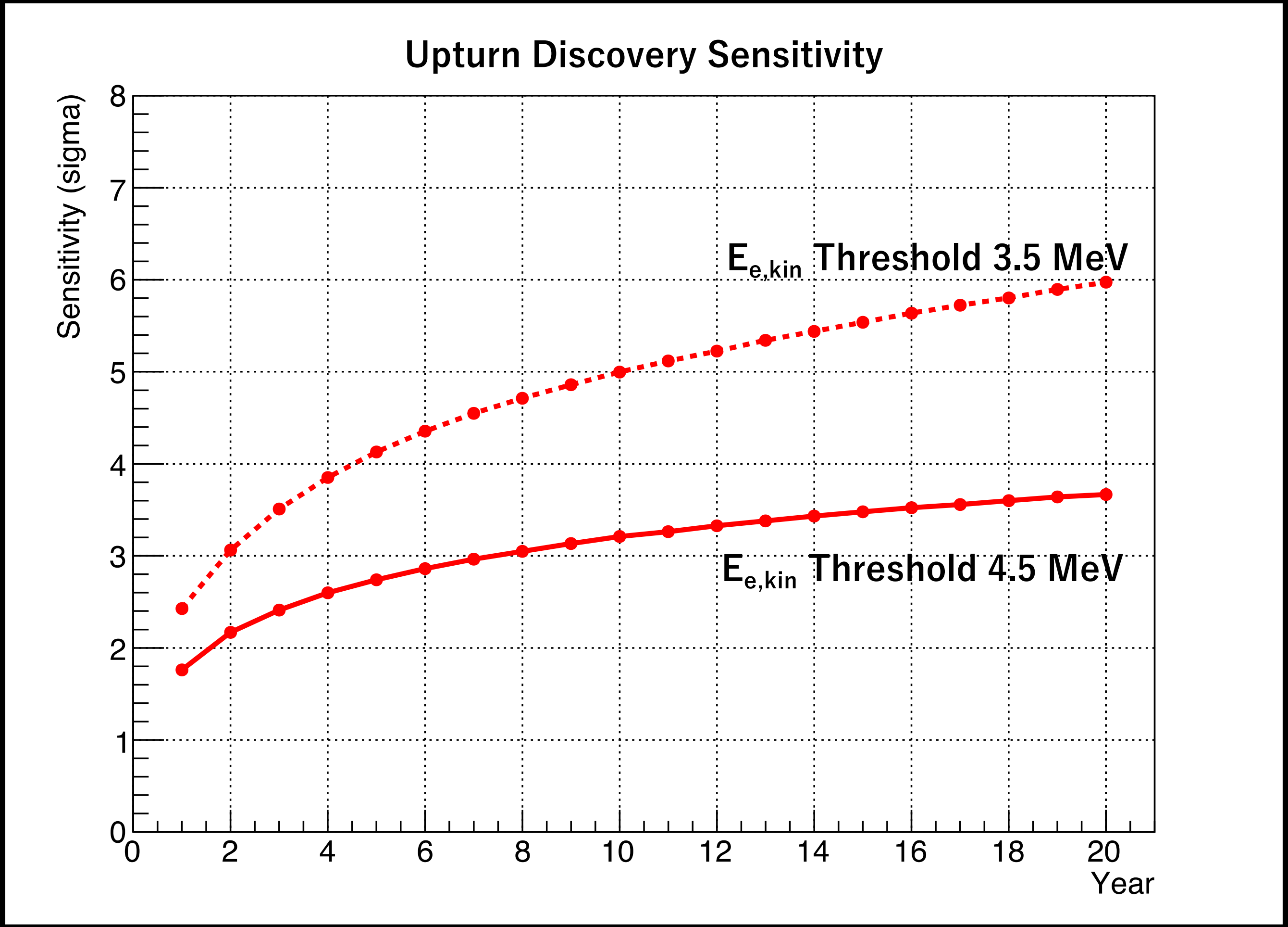
Expect to see ~180 ^{8}B Solar neutrinos (>5 MeV) / day in Hyper-K

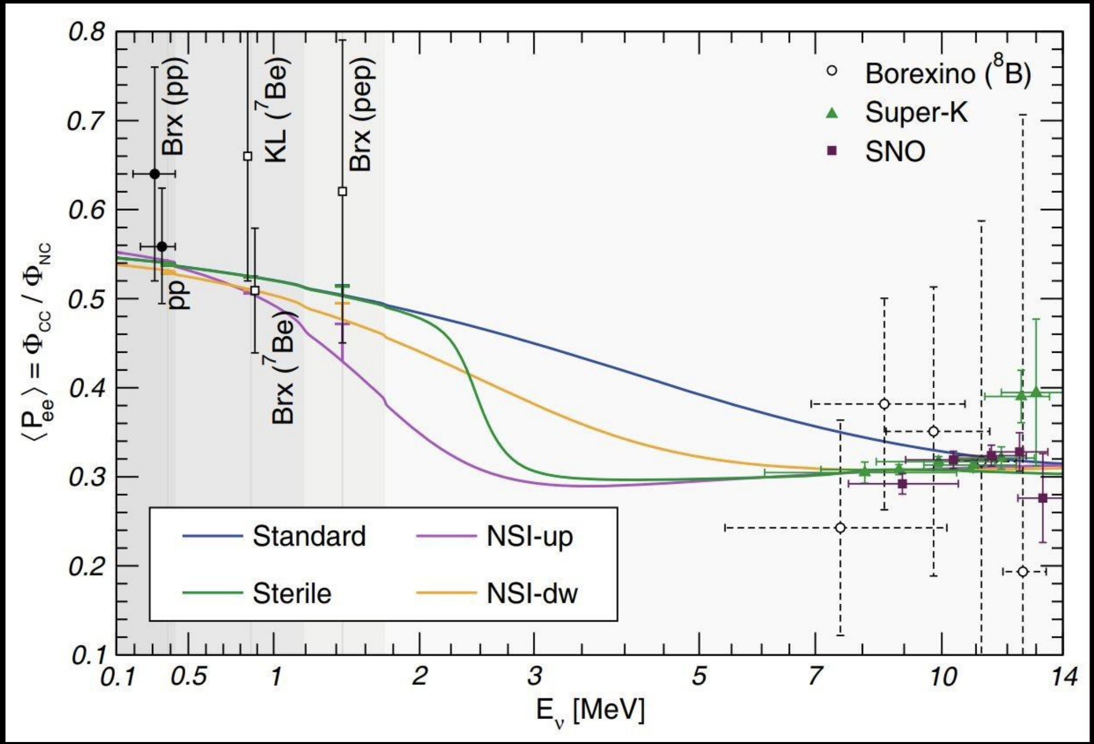
Day-night asymmetry observation sensitivity

- red line = sensitivity from no asymmetry
- blue line = asymmetry expected by the reactor neutrino oscillation ($\Delta m^2_{21} = 7.54 \times 10^{-5}\ eV^2$)
- Systematic from remaining background direction 0.3% (solid) 0.1% (dashed)

Hyper-K can reject no D/N asymmetry at >5σ with 10 years of data and can investigate this tension with increased statistics

Solar Neutrinos - 8B Spectrum Upturn



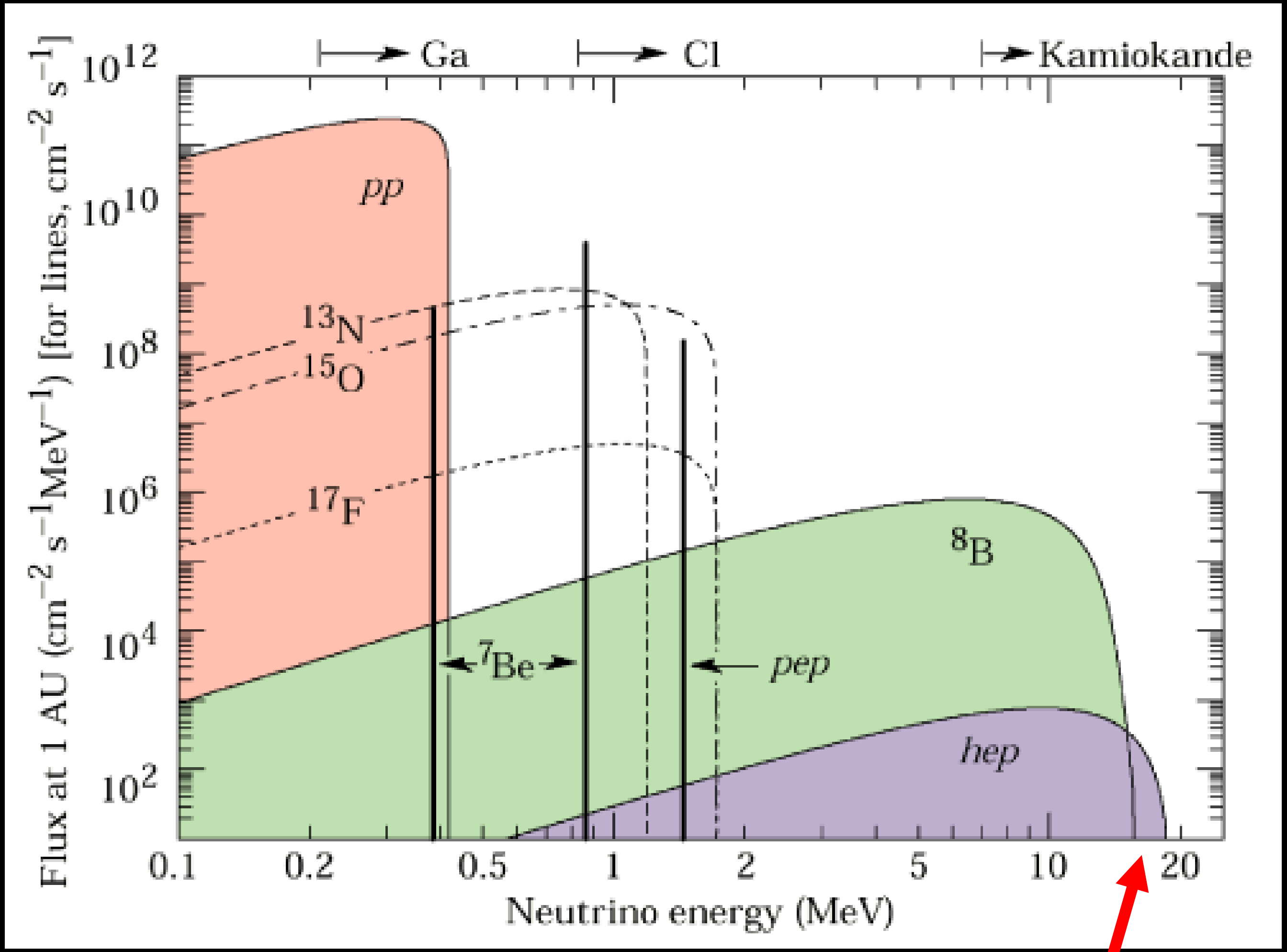


Sensitivity of 3-5σ for upturn discovery after 10 years of Hyper-K running

- Measurement of upturn could distinguish standard neutrino oscillations from several different exotic models
- Low energy spectrum upturn sensitivity as a function of observation time for two different detection thresholds

Solar hep Flux

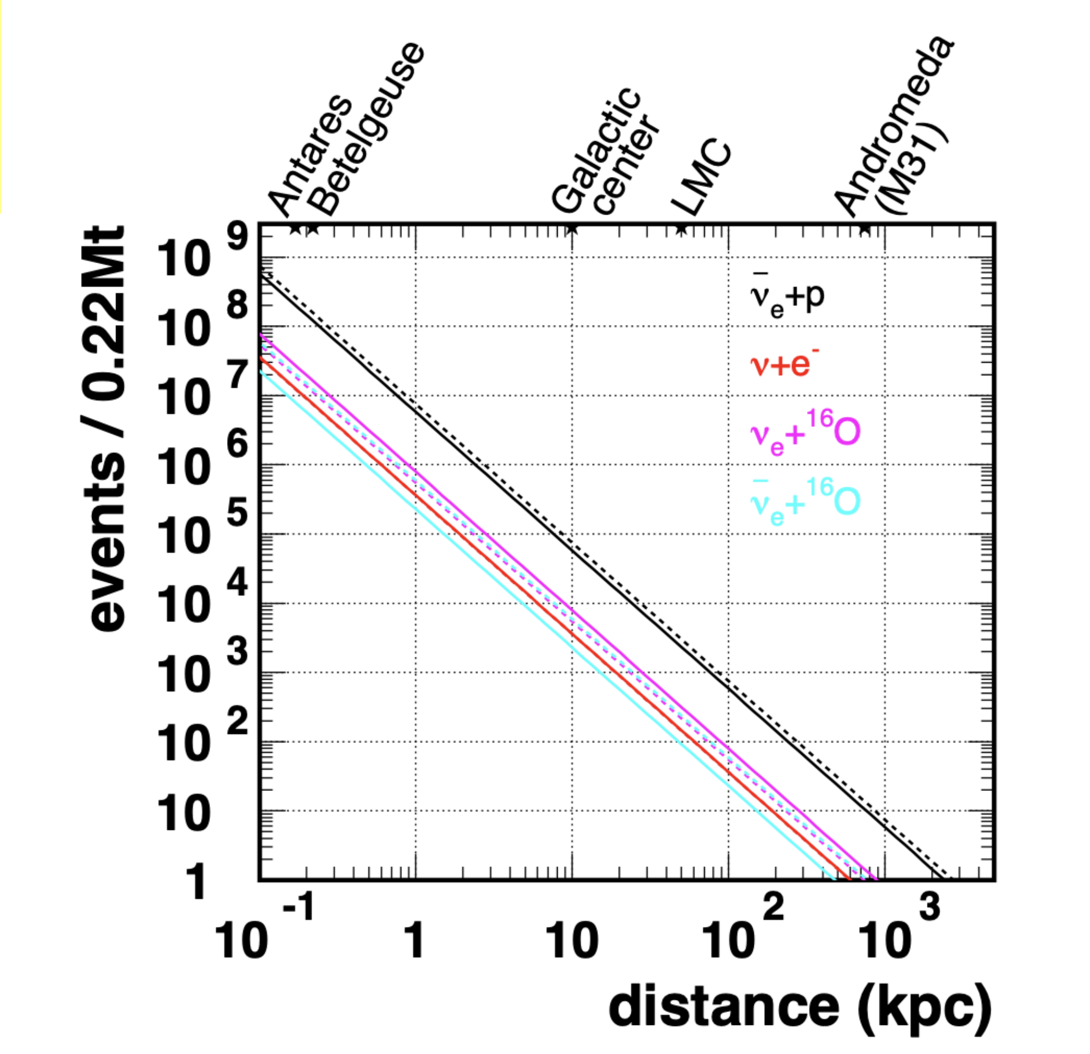
- $^3He + p \rightarrow \ ^4He + e^+ + \nu_e$
- Flux never been observed
  - Upper limits from SNO and SK
- Chance to perform first observation in Hyper-K
  - Challenge is separation from atmospheric spallation backgrounds



Look in this energy window

Supernova Bursts

DAQ designed to cope with peak data rates from very close SN (eg. Betelgeuse)



Expected number of events at Hyper-K as a function of Supernova distance
Using Totani et al model

Astrophys.J. 916 (2021) 15

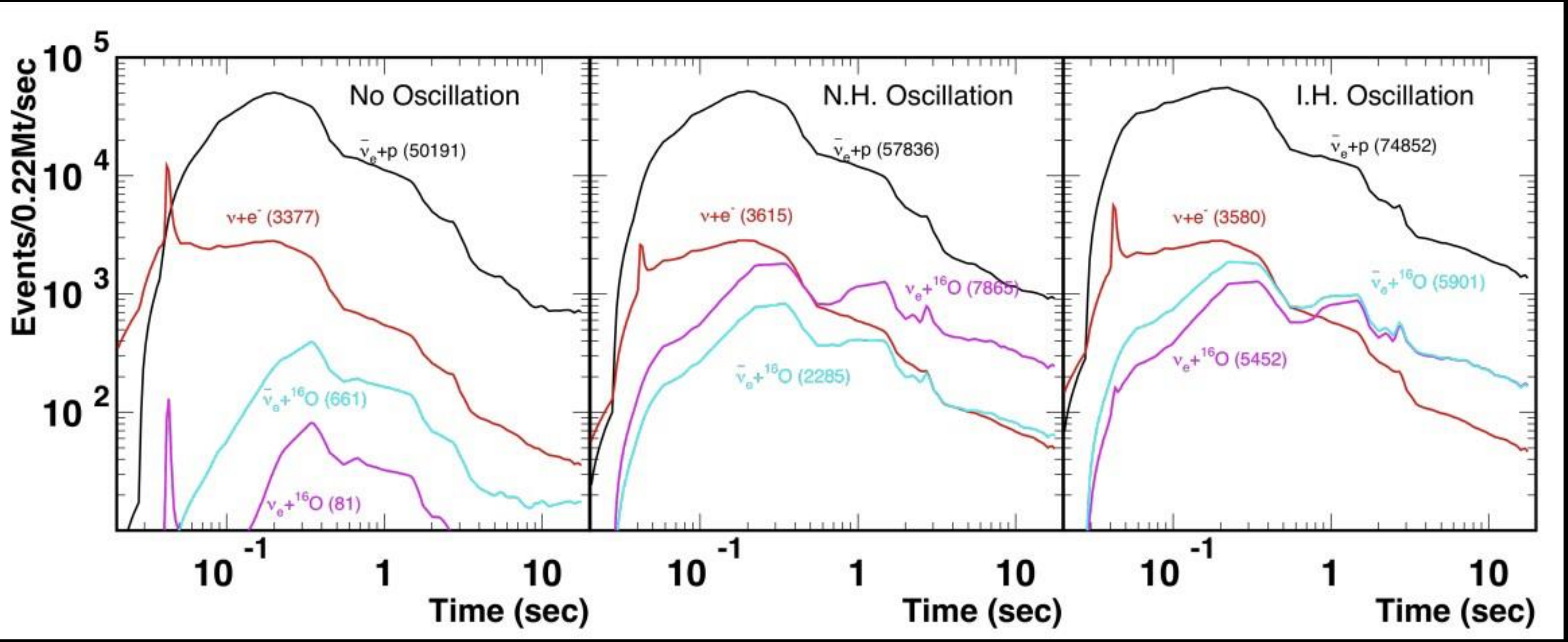
Hyper-K will contribute to SNEWS (supernova early warning system)

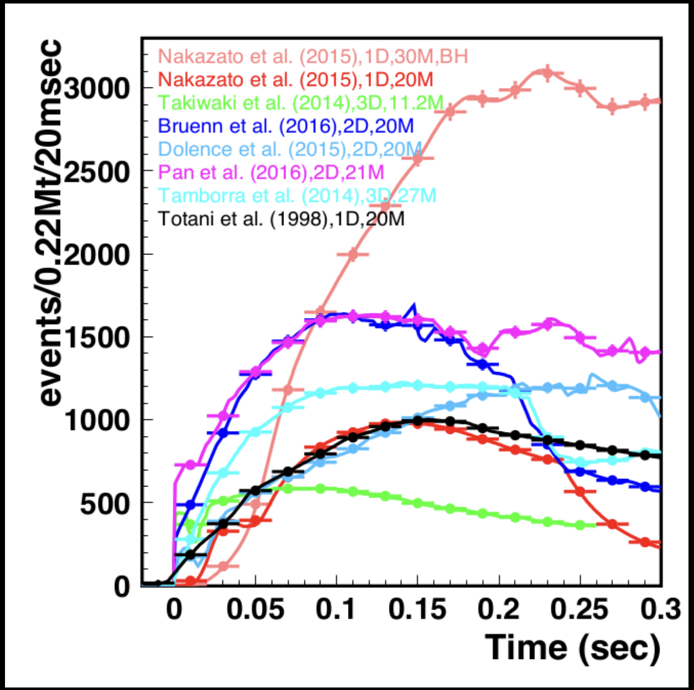
- Water Cherenkov approach gives 1.3° pointing accuracy
- ~1000 ES events > 5MeV (10kpc SN)

Neutrino Astrophysics – Supernova Bursts

Astrophys.J. 916 (2021) 15

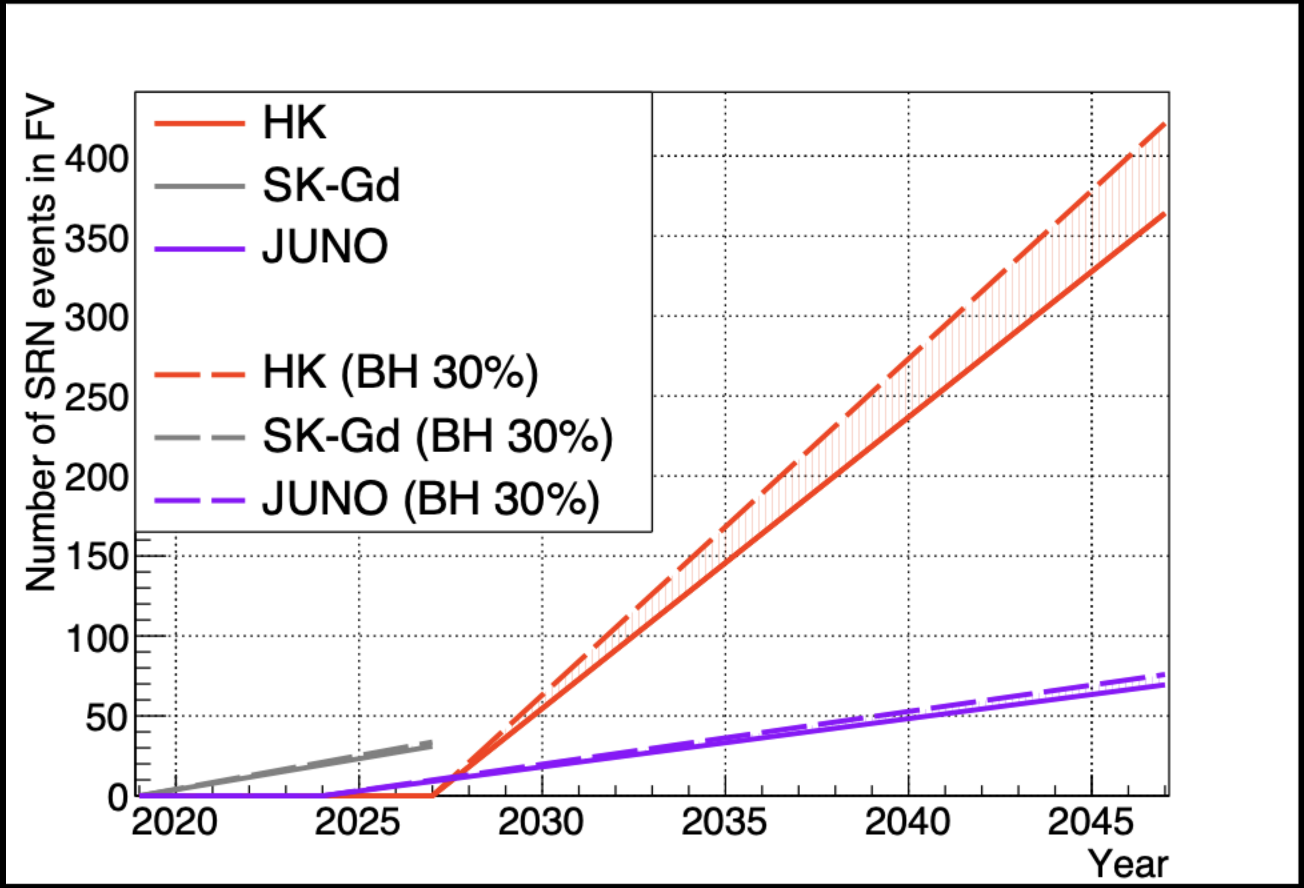
- Expected time profile and event numbers in HK for a supernova at 10 kpc (Livermore simulation)
  - numbers in brackets are total interactions integrated over the 10 s burst
  - peak event rate of inverse beta decay events (black) reaches ~50 kHz
  - Model discrimination



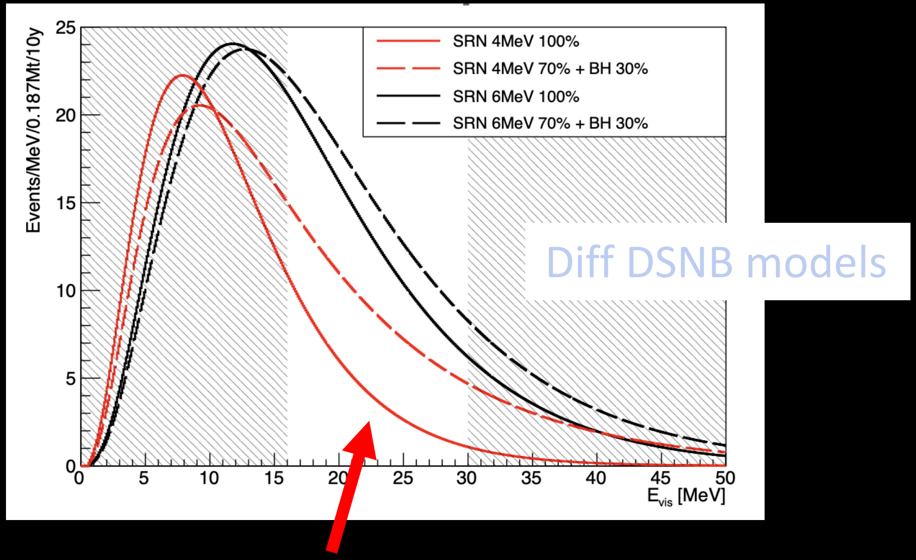


Diffuse Supernova Neutrino Background (DSNB)

Expected number of DSNB IBD reactions as a function of year



Dashed lines corresponds to the case, in which 30% of the supernovae form black holes and emit higher energy neutrinos corresponding to the neutrino temperature of 8 MeV



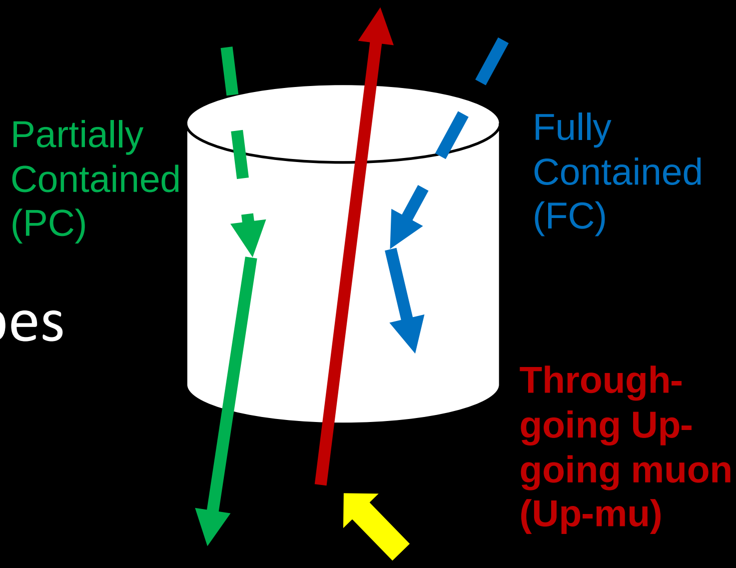
Look in this energy window

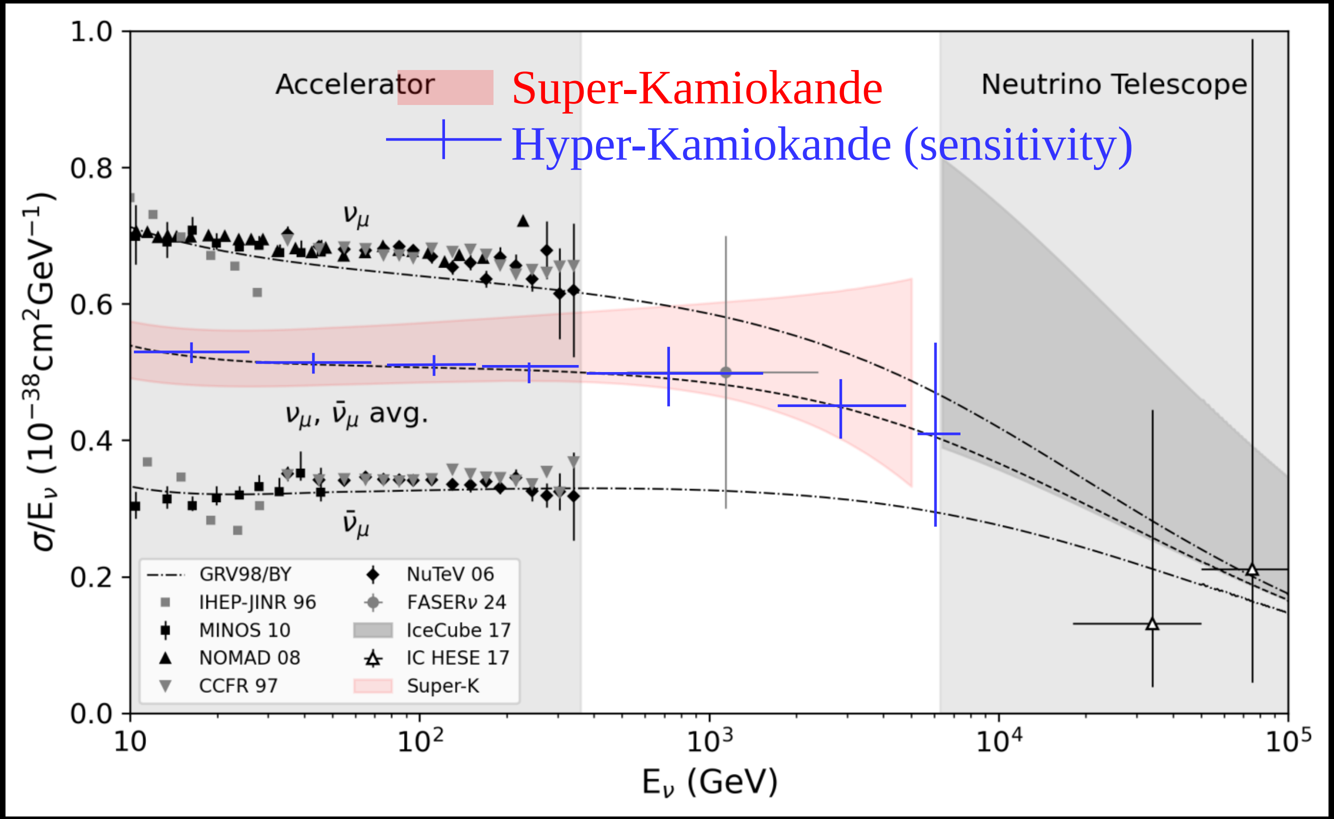
Challenge is separation from atmospheric spallation backgrounds

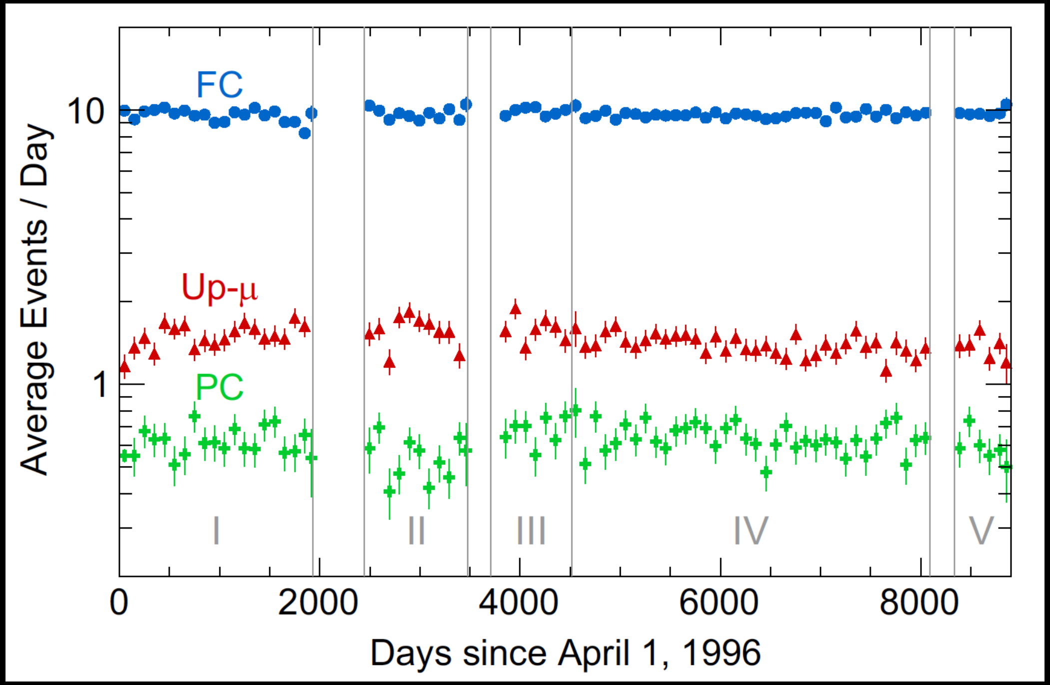
4.2 (5.7) sigma discovery potential after 10 (20) years, with 70 (140) signal events

High Energy Astrophysical Neutrinos

- ~1000 events/yr in TeV region from upgoing muon sample
  - Fill the “gap” between accelerator neutrinos and neutrino telescopes
  - Prompt neutrinos, galactic plane neutrinos, etc







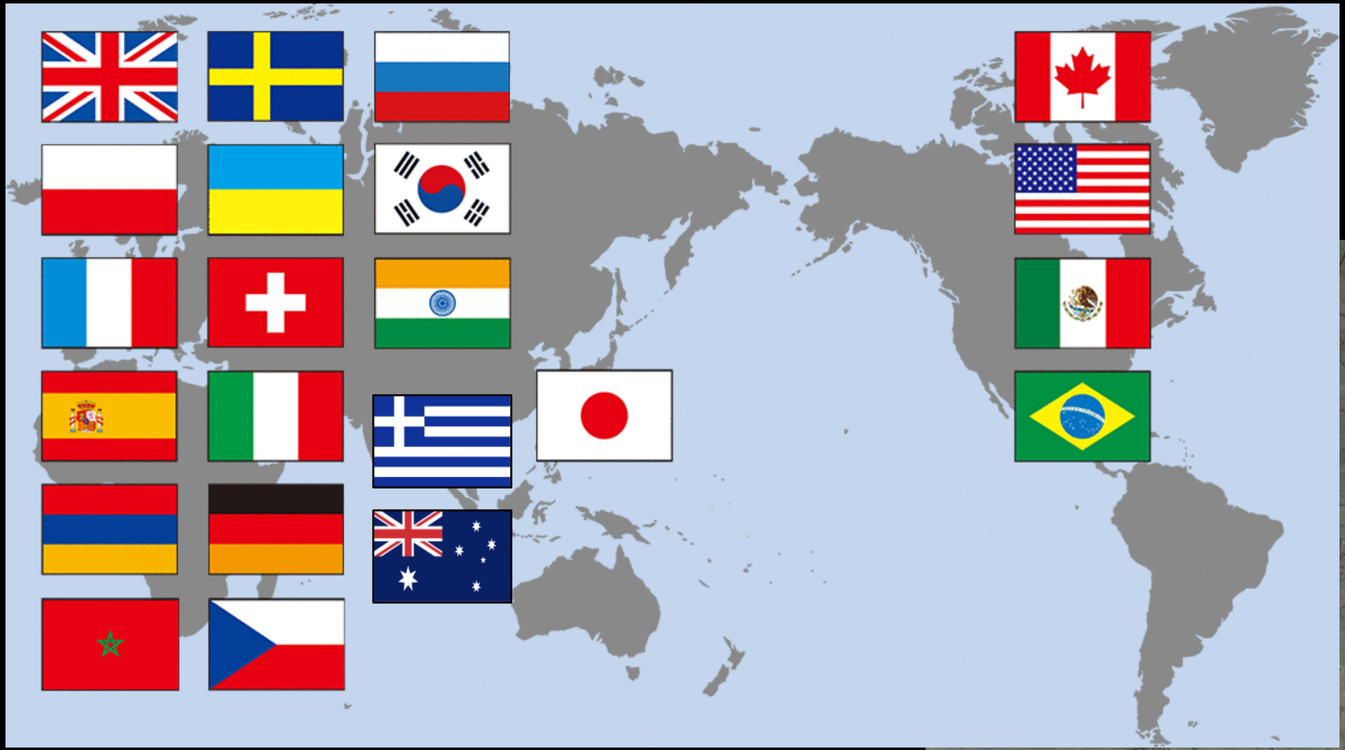
Super-K event rates

Summary

In addition to the Hyper-K long-baseline programme to address CP violation and neutrino oscillation physics - with beam + atmospheric neutrinos - Hyper-K has a vibrant non-beam programme:

- Proton Decay – world-leading sensitivities in many channels
- Solar Neutrinos – potential to measure day-night asymmetry, MSW low energy upturn and hep-neutrinos, probe tension with reactor measurements and test for new physics
- Supernova burst – potential to observe SN $0.1 \rightarrow \sim 10^3$ kpc and discriminate between different models
- DSNB – discovery potential

Hyper-Kamiokande Collaboration



22 countries, 104 institutes, 583 members as of 1/4/2024

Still increasing

Hosts:

- University of Tokyo
  - Hyper-K far detector
- KEK/JPARC
  - Beam and Near Detectors

October 2023

Other Hyper-K talks

151. Outer Detector System R&D for Hyper-Kamiokande
Teppei Katori
12/06/2025, 15:30
Astroparticle

28. Long Baseline Neutrino Experiments
Patricia Vahle
13/06/2025, 09:30
Plenaries