Status, plans, and physics potential

of the Hyper-Kamiokande experiment

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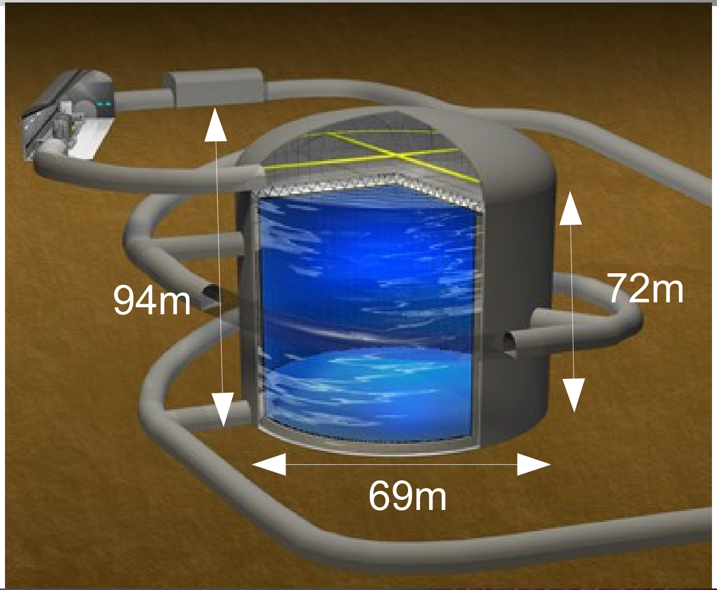
Outline

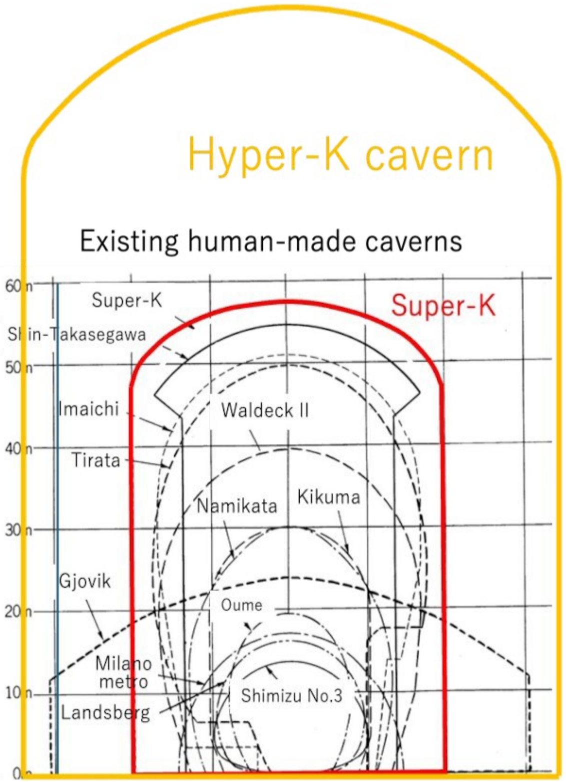
- technical design of Hyper-Kamiokande
  - successor of successful Water Cherenkov experiments in Japan
    - KamiokaNDE: 1983-96
    - Super-Kamiokande (+K2K, +T2K): 1996-...
  - mature and scalable technology
- physics program
- status and plans



Collaboration:
106 institutes
from 22 countries
~650 members
(~75% non-Japanese)

Basic informations

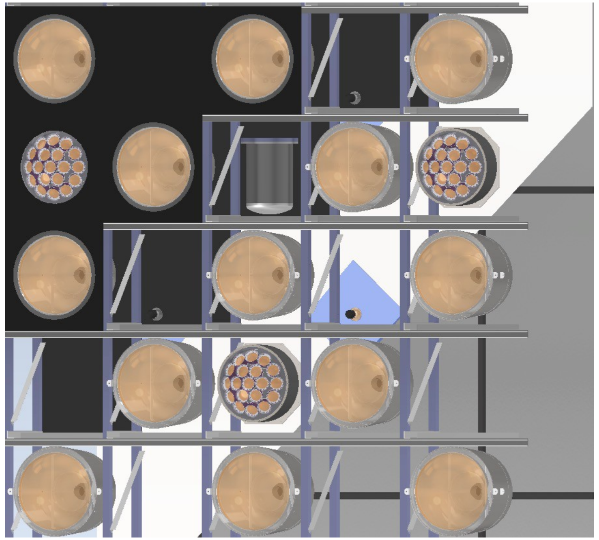
- total mass 258 t (187 t FV = 8.4 · Super-K)
    - the largest ever human-built cavern!
    - ~8 bars of water pressure at the tank bottom
- ~20 000 20" PMTs in the Inner Detector (20% photocoverage)
- ~800 multi PMTs
- ~3600 3" PMTs on Wave Length Shifter plates in the Outer Detector (1m wide)
- 900 electronic modules in underwater vessels

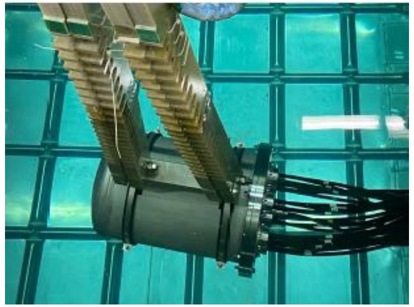


stainless steel frame

70 cm x 70 cm grid

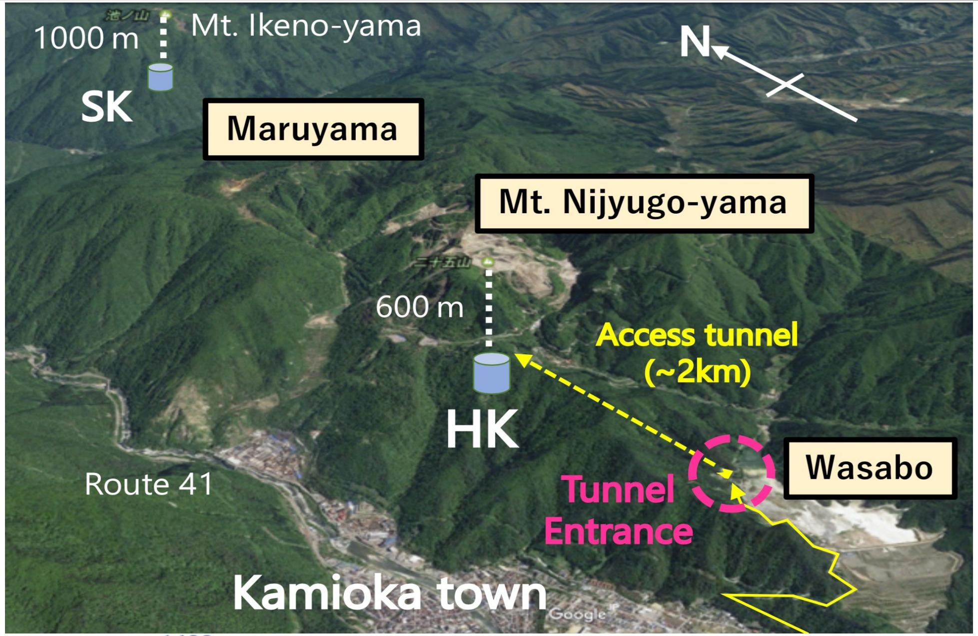
Tyvek and black sheets

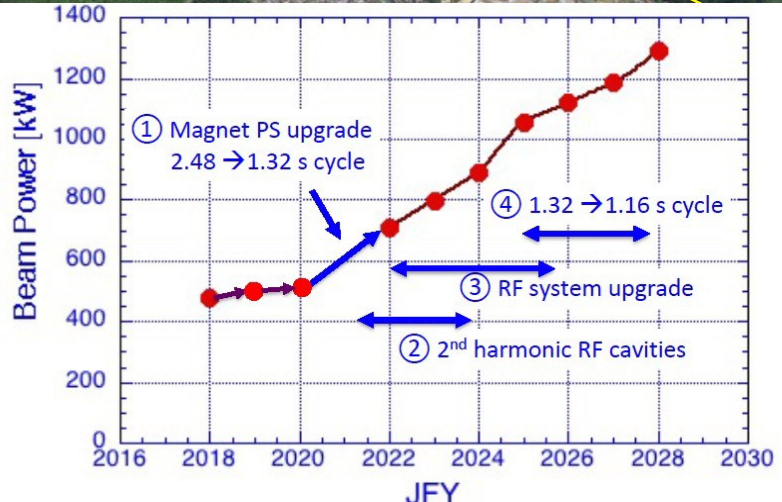




Location and ν beam from J-PARC

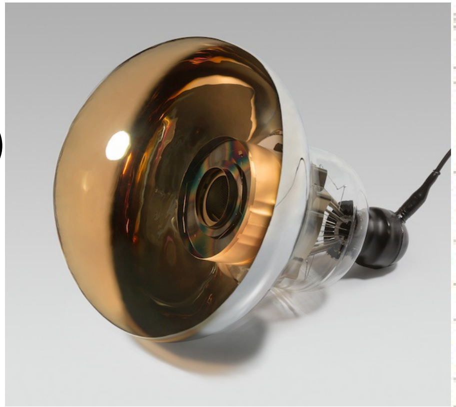
- detector site 8 km south of SK
  - shallower rock overburden (600 m)
  - the same baseline (295 km) and off-axis angle (2.5°) wrt J-PARC as SK
- upgrade of ν beam from J-PARC
  - 830 kW achieved this year
  - → 1.3MW (2028)
  - 2.6E14 → 3.2E14 protons per pulse
  - cycle 2.48 s → 1.36 s (now) → 1.16 s
- upgrade power supplies for horns
  - 250 kA → 320 kA current (now)
  - 10% higher neutrino flux
  - reduction of wrong-sign neutrino contamination by 5-10%

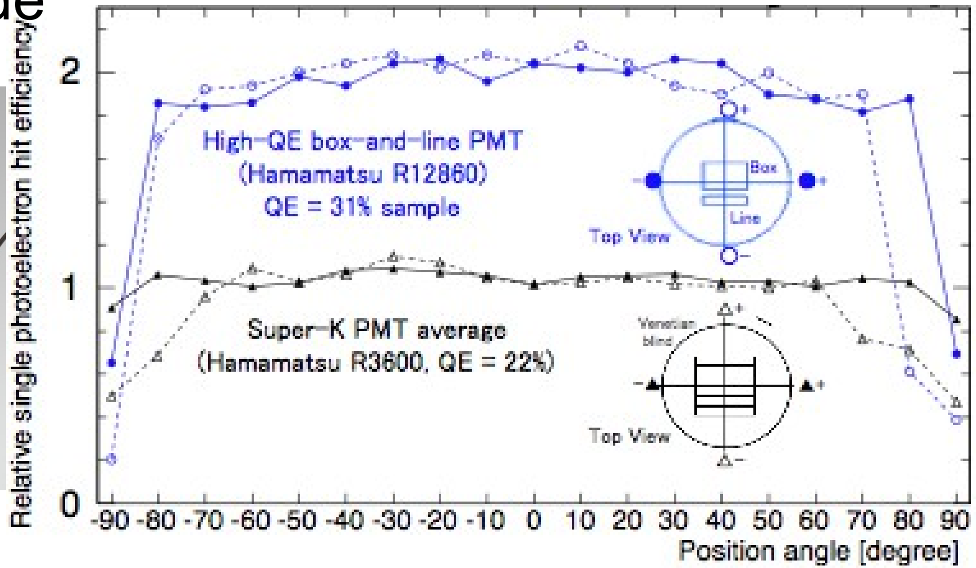


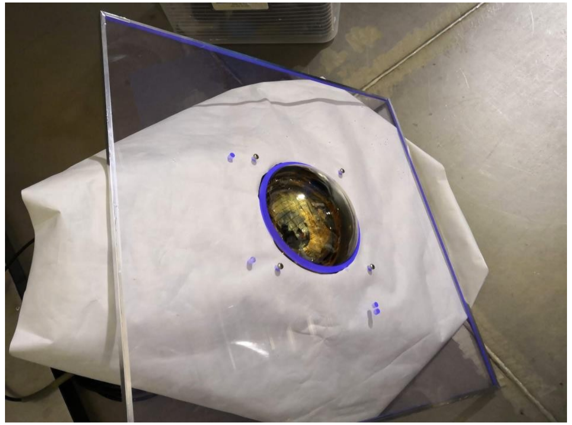


The photodetectors

- Hamamatsu 50cm B&L PMT with improved dynode and higher pressure tolerance
  - 2x better photon efficiency (30%)
  - 2x better charge resolution (30%) and timing resolution (1 ns)
  - same dark rate (4 kHz)
  - performance tested in Super-K (134 installed in 2018)
- ~800 multi PMTs: 19x3" PMTs to improve reconstruction in the detector corners
- Outer Detector: ~3600 3" PMTs on Wave Length Shifter plates
- covers to protect PMT from sudden pressure changes



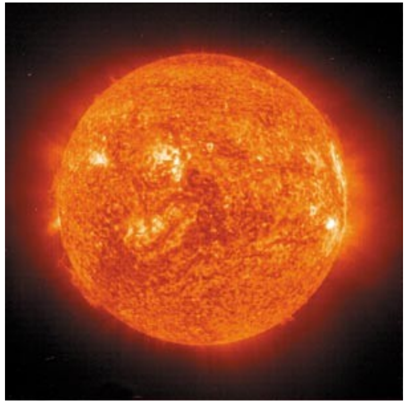




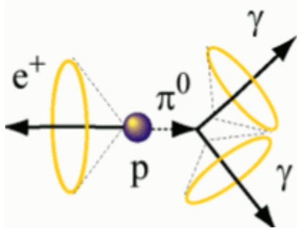
Physics program

- neutrino astrophysics
  - precise measurement of solar neutrinos, sensitivity to address solar and reactor neutrinos discrepancy
  - supernova burst and relic supernova neutrinos
- neutrino oscillations
  - with atmospheric and beam neutrinos
  - CP violation
  - precise measurement of θ_{23}
  - mass ordering determination
- searching for nucleon decay
  - sensitivity ~10x better than Super-K
  - all visible modes can be advanced
- and other

next talk



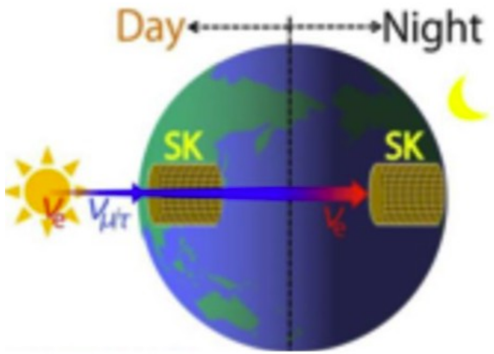


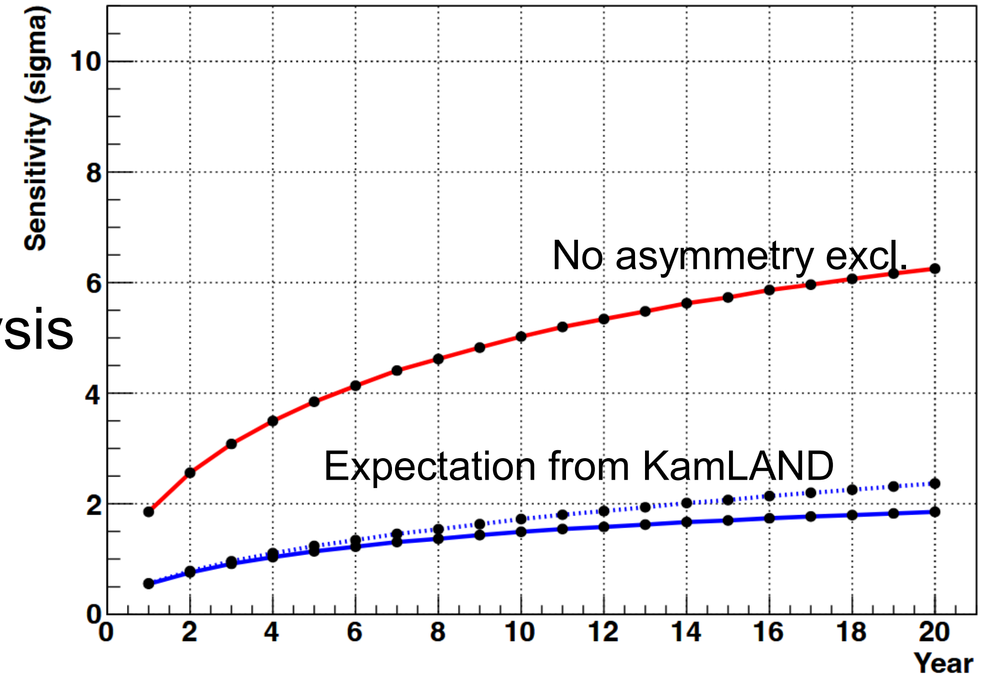


Solar neutrinos

- huge statistics in HK: ~5 ^8B ν/hour
- precise measurement of Δm^2_{21} and day-night asymmetry caused by electron component regeneration in Earth (3σ indication in Super-K)
  - few percent higher event rate at night
  - asymmetry magnitude depends mostly on Δm^2_{21}
- tension ~1.5σ in Δm^2_{21} between KamLAND (reactor) and global solar analysis

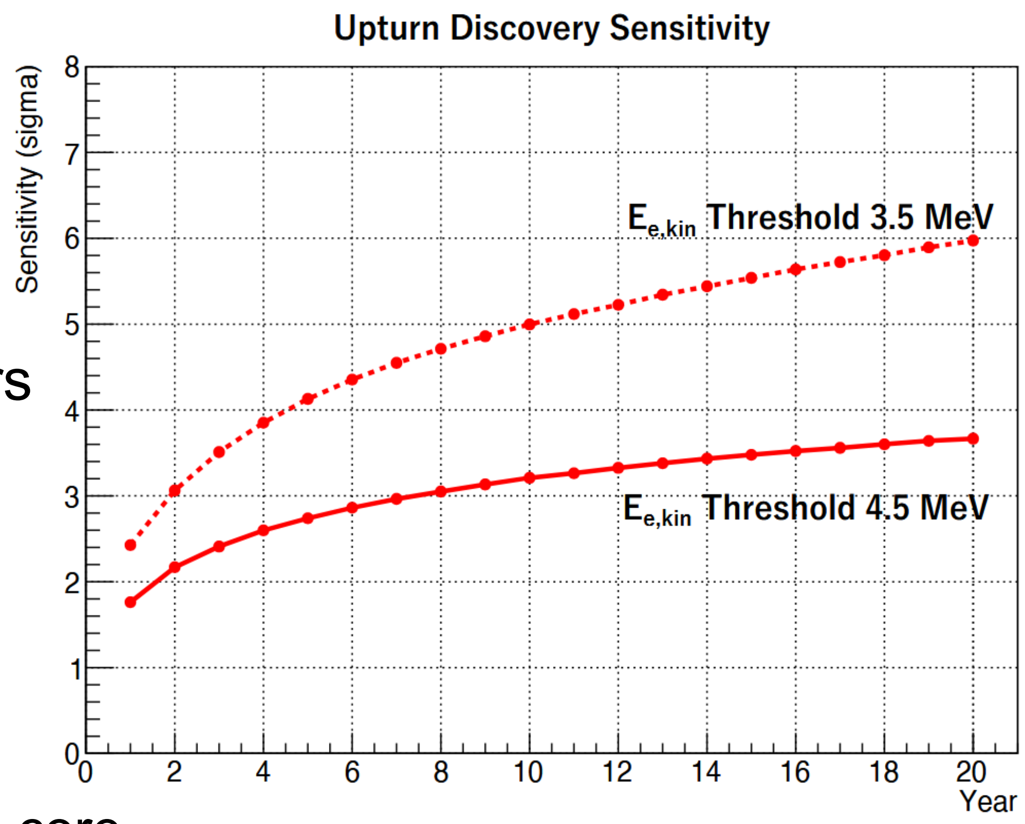
- new physics needed if the tension is a real effect





Solar neutrino spectrum upturn

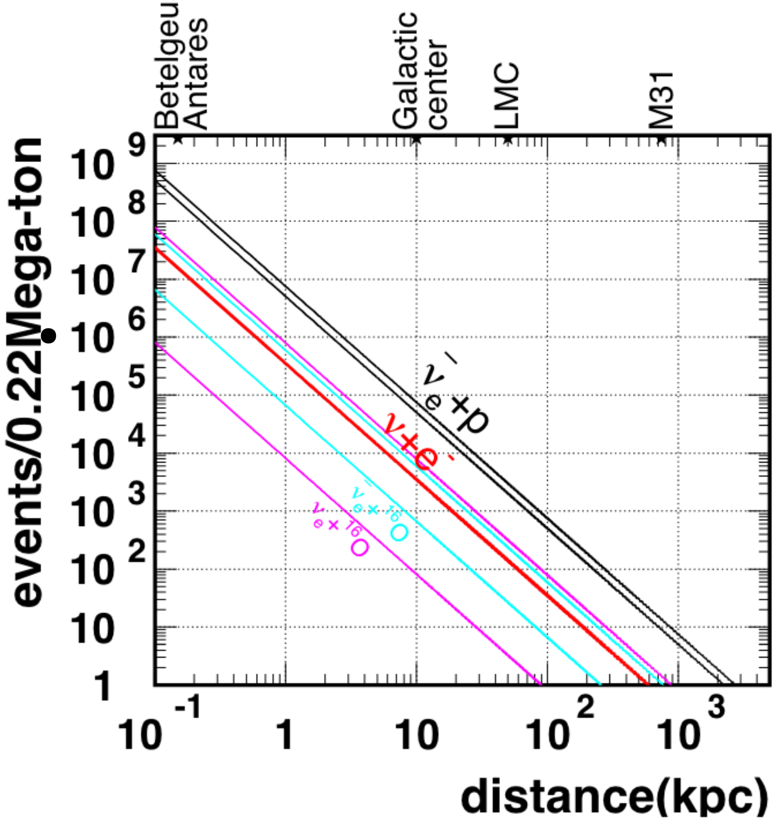
- transition region between the vacuum oscillations and matter-dominated energy regions
- precise measurement of the spectrum shape allows to distinguish the usual neutrino oscillation scenario from exotic models
- 3σ sensitivity to spectrum upturn in 10 years for 4.5 MeV threshold
  (5σ for 3.5 MeV threshold)



- other possible measurements
  - first measurement of *hep* component (2-3σ) providing more information on the Sun core
  - time variation measurement (with rate of 130ν/day) → monitoring of the Sun core temperature

Supernova burst neutrinos

- ν_e from neutronization peak – elastic scattering on electrons (directional information, accuracy 1-1.3° expected for supernova @10kpc)
- $\bar{\nu}_e$ from cooling phase – inverse beta decay



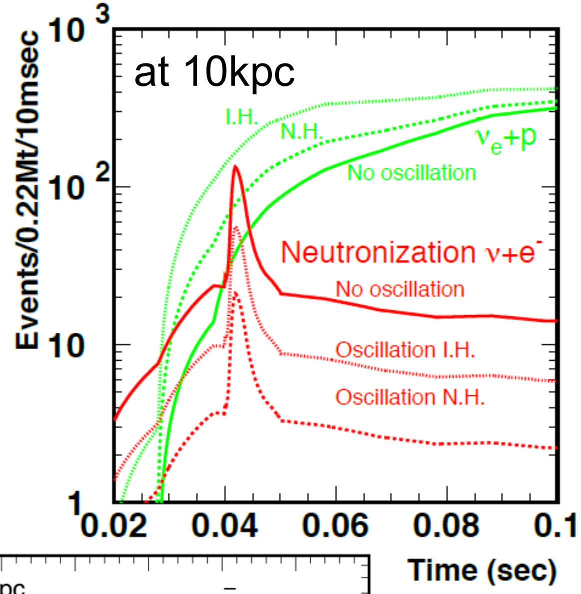
<u>expectations</u>:

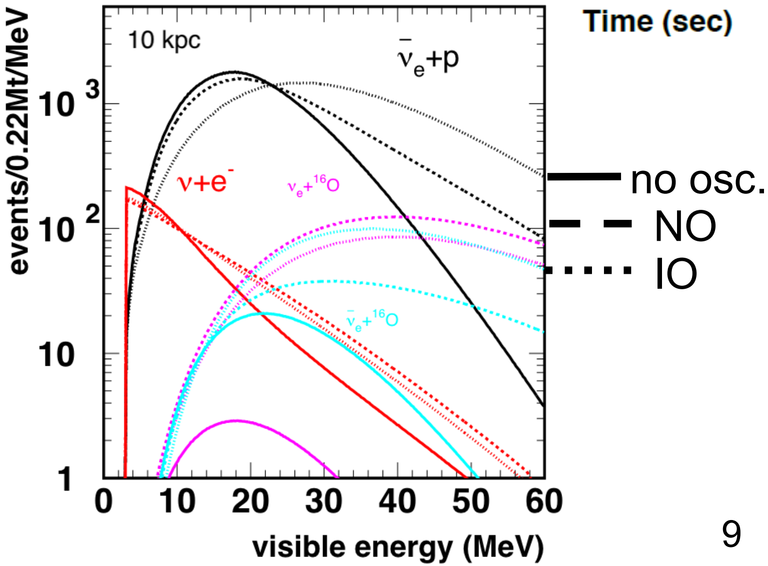
~70k events @10kpc
2-3k (SN1987a)

<u>information on</u>

- neutrino oscillations and properties (mass, mass ordering)
- core-collapse supernova models

Early warning for telescopes



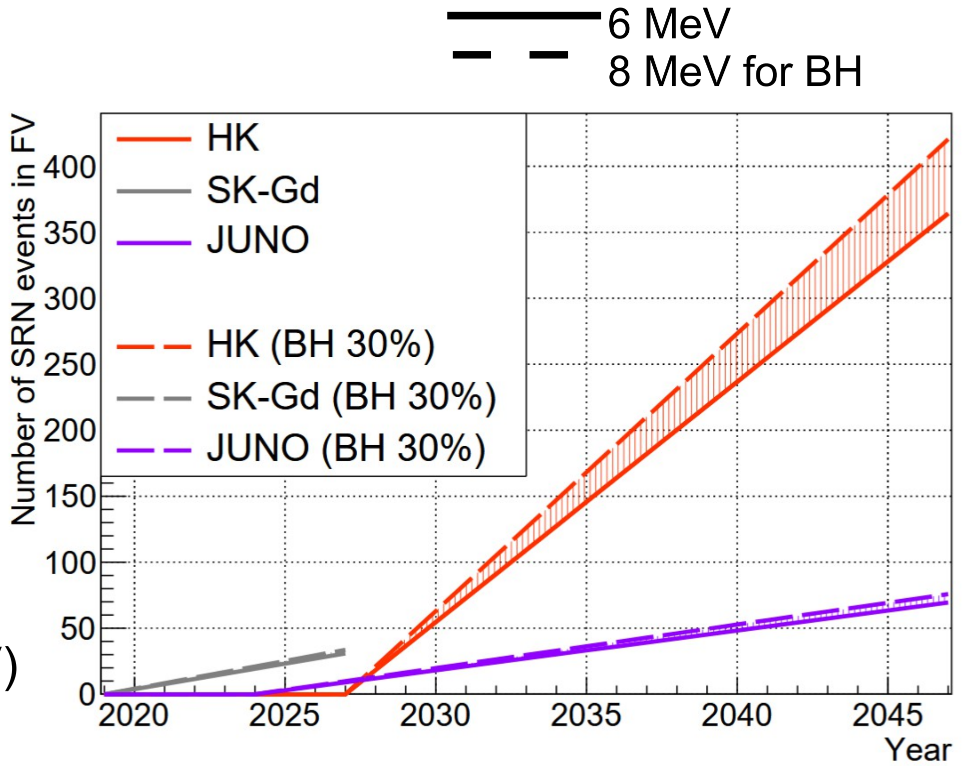


Supernova relic neutrinos

or: diffuse supernova neutrino background

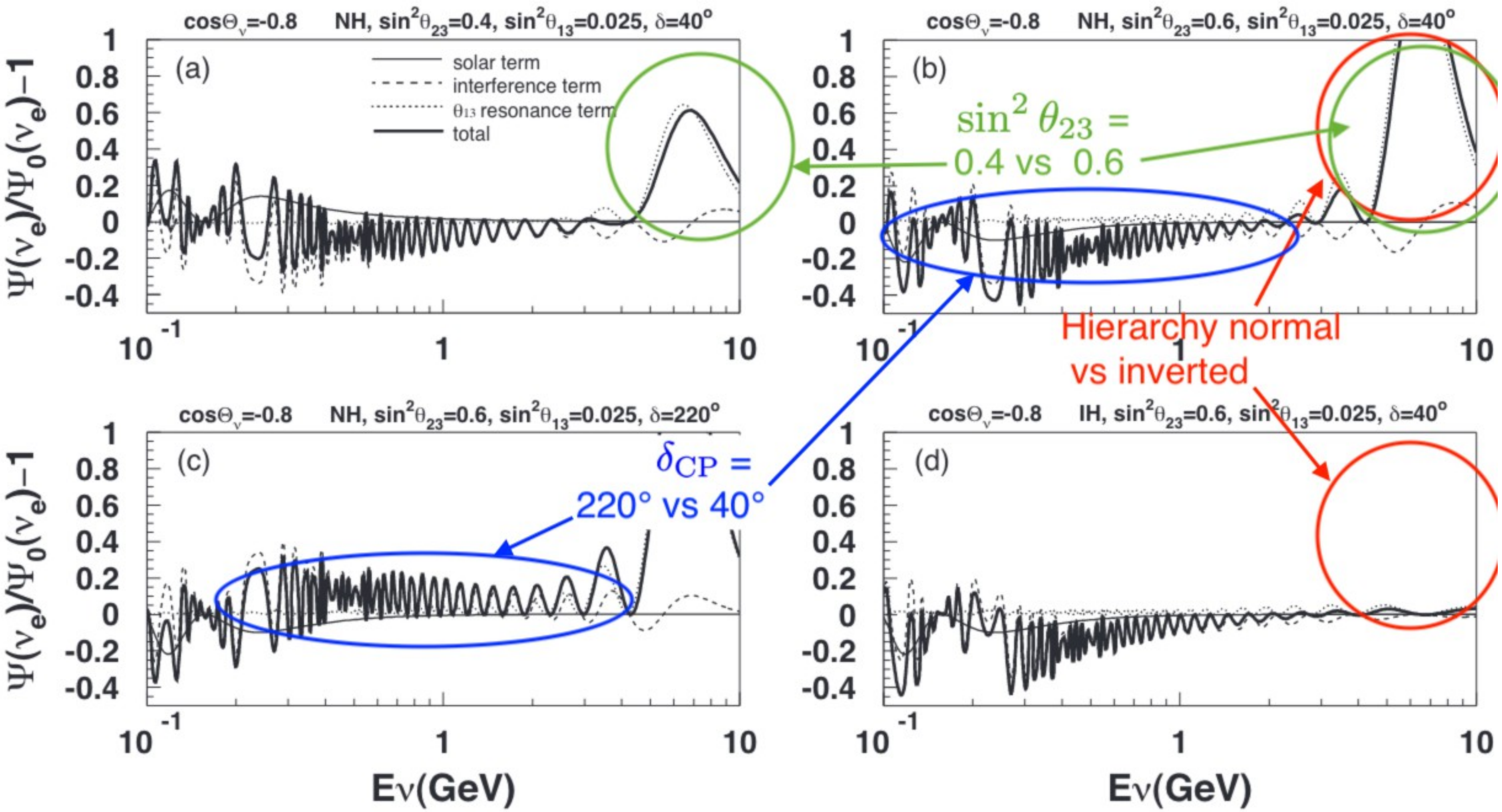
- expected flux few tens/cm^2·s
- search limited by background:
  - spallation for low energies
  - atmospheric neutrinos for high energies
- first measurement may be done by SK-Gd
- Hyper-K may measure the spectrum
- different search window (~16-30 MeV)
  - complementary to SK-Gd searches (10-20 MeV)
  - contribution of extraordinary supernova bursts (like black hole formation, BH): provides information on the star formation history and metallicity

expected inverse beta decay events



Atmospheric neutrinos

- study of oscillations for wide range of energies and baselines
- matter effects in the Earth affect flux of electron neutrinos:
  - presence of a resonance in multi-GeV region → mass ordering
  - magnitude of the resonance → θ_{23} octant
  - scale and direction of the effect at 1 GeV → δ_{CP}

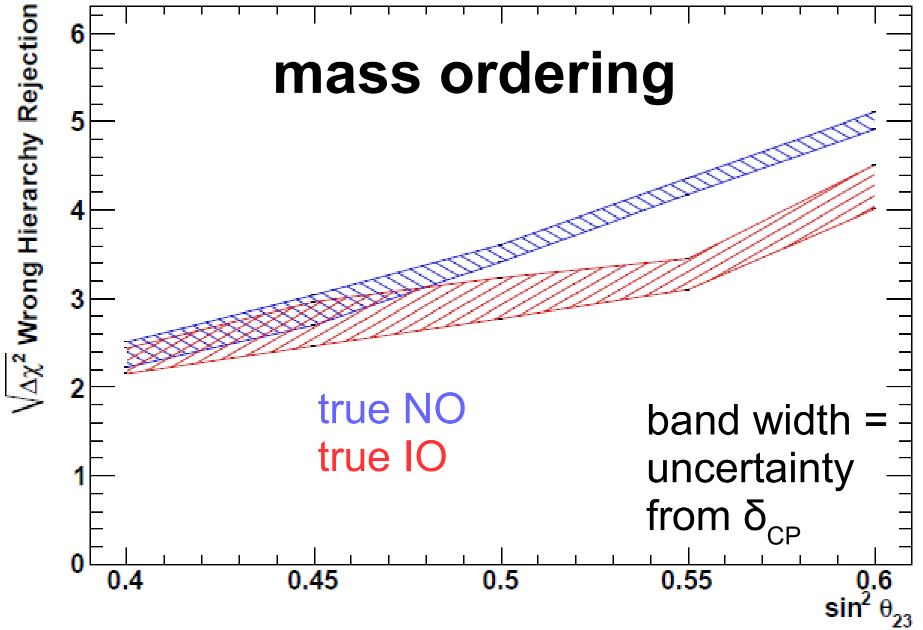


ν_e flux relative to no oscillations,

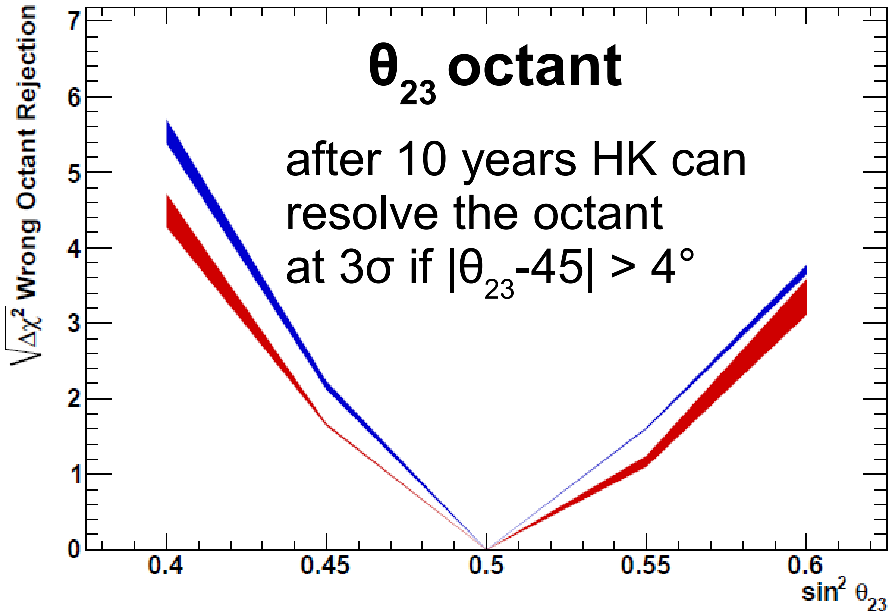
plots for cosθ=0.8

Atmospheric neutrinos

- large statistics: ~80 events/day expected



10 years = 1.9 Mton·year exposure



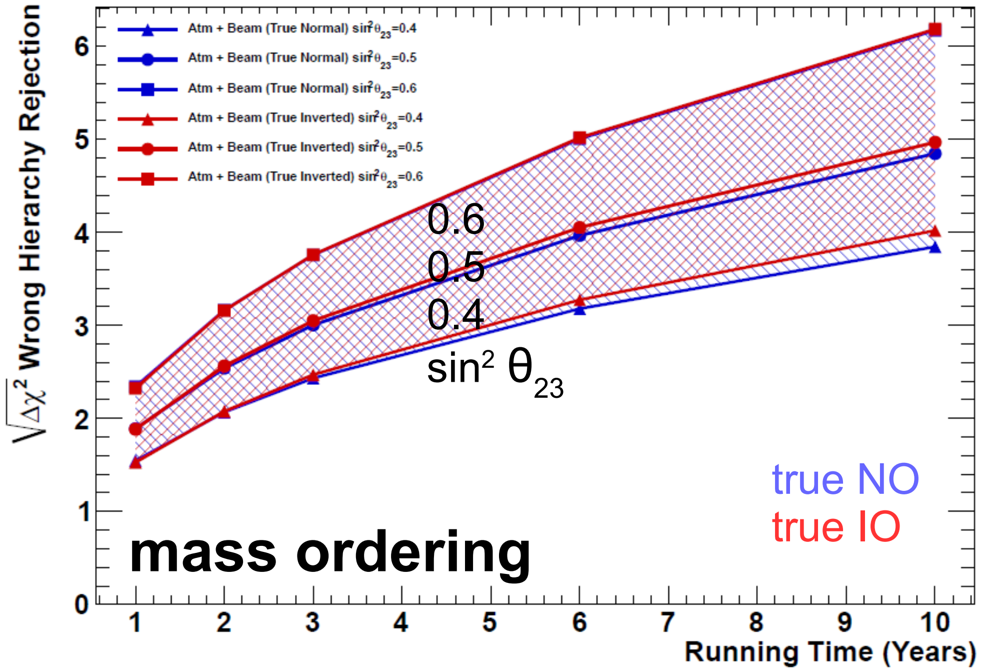
- tau neutrino appearance and cross-section
- exotic physics: Lorentz invariance violation, non-standard neutrino interactions
- primary atmospheric neutrino flux
- some sensitivity to chemical composition (electron density) of Earth's Outer Core

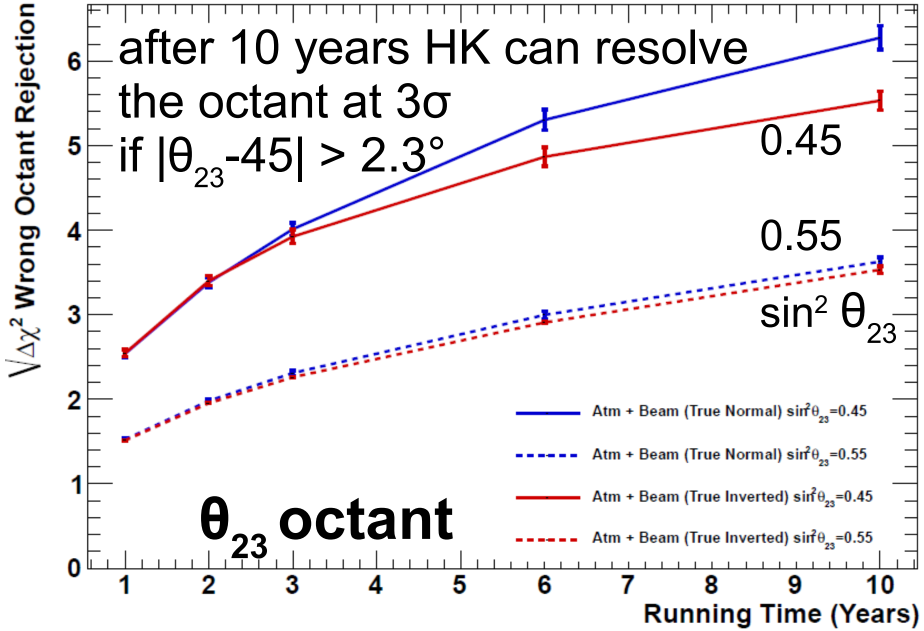
Atmospheric+beam neutrinos

- combined analysis allows to:
  - resolve parameters degeneracy
  - achieve better sensitivity to oscillation parameters
- atm. neutrinos are also used to constrain systematic uncertainties related to detector effects and cross-section

	$\sin^2\theta_{23}$	Atmospheric neutrino	Atm + Beam
Mass ordering	0.40	2.2 σ →	3.8 σ
	0.60	4.9 σ →	6.2 σ
θ_{23} octant	0.45	2.2 σ →	6.2 σ
	0.55	1.6 σ →	3.6 σ

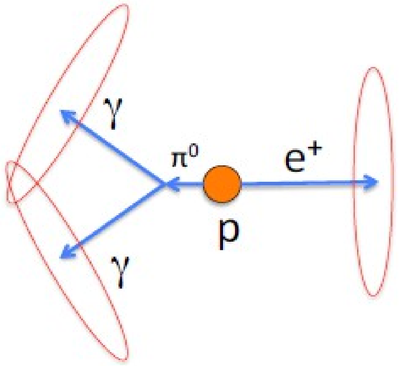
10 years with 1.3MW, normal mass ordering is assumed





Search for $p \rightarrow e^{+}\pi^{0}$ decay

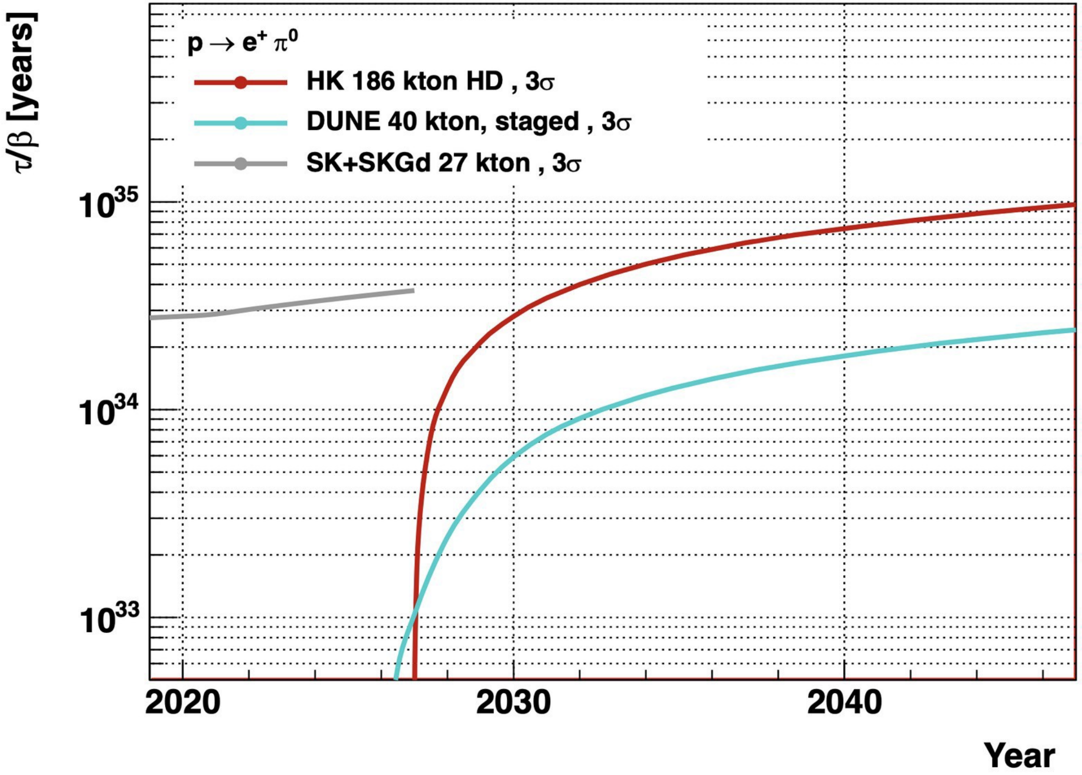
- decay mode $p \rightarrow e^{+}\pi^{0}$ favoured by many GUTs



e^{+} and photons detected as e-like rings
→ final state is fully reconstructed
(almost background free)

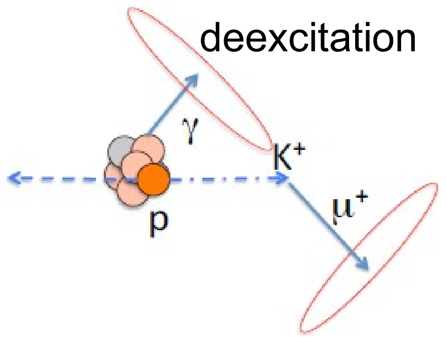
- analysis similar as in SK
  - neutron capture in water: n(p,d)γ (2.2 MeV)
  - efficient tagging of prompt γ from residual nuclei deexcitation
  - → ~50% reduction of atmospheric background

Expected 90% C.L. limits



Search for $p \to \bar{\nu} K^+$ decay

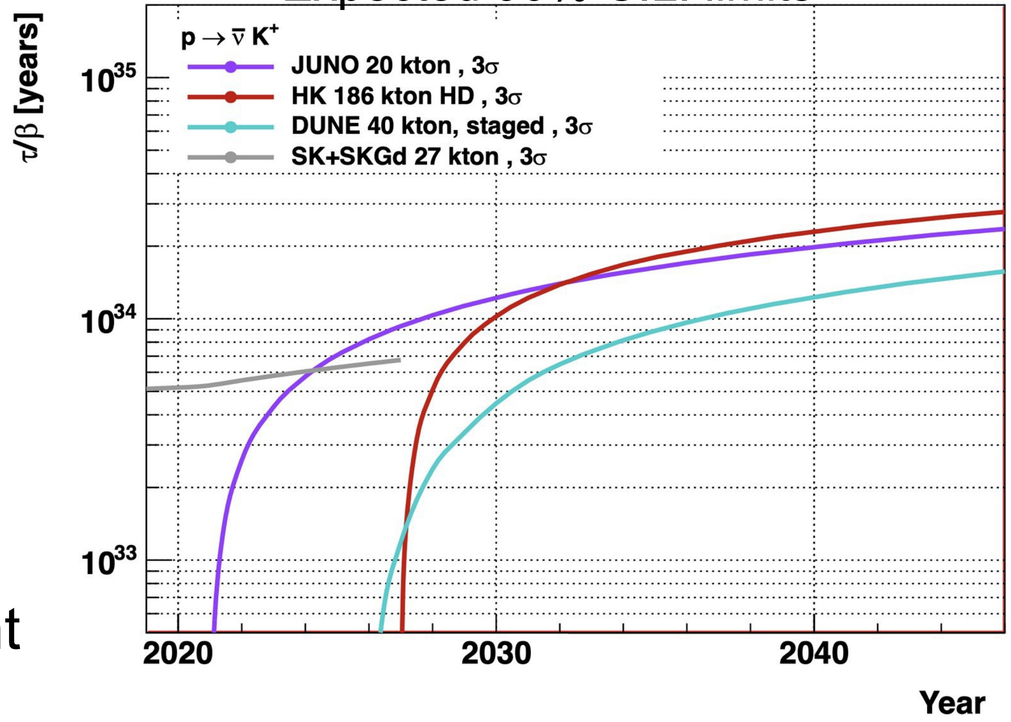
- favoured by SUSY GUTs
- kaon not visible in Water Cherenkov detector: reconstructed from decay products
  - monochromatic muon (236 MeV) +prompt deex. photon (6.3 MeV) } $K^+ \to \mu^+ \nu$, BR 64%
  - excess in muon spectrum
  - or search for $K^+ \to \pi^0 \pi^+$ decay (BR 21%, $p_{\pi+}$ = 205 MeV/c, slightly above the threshold)



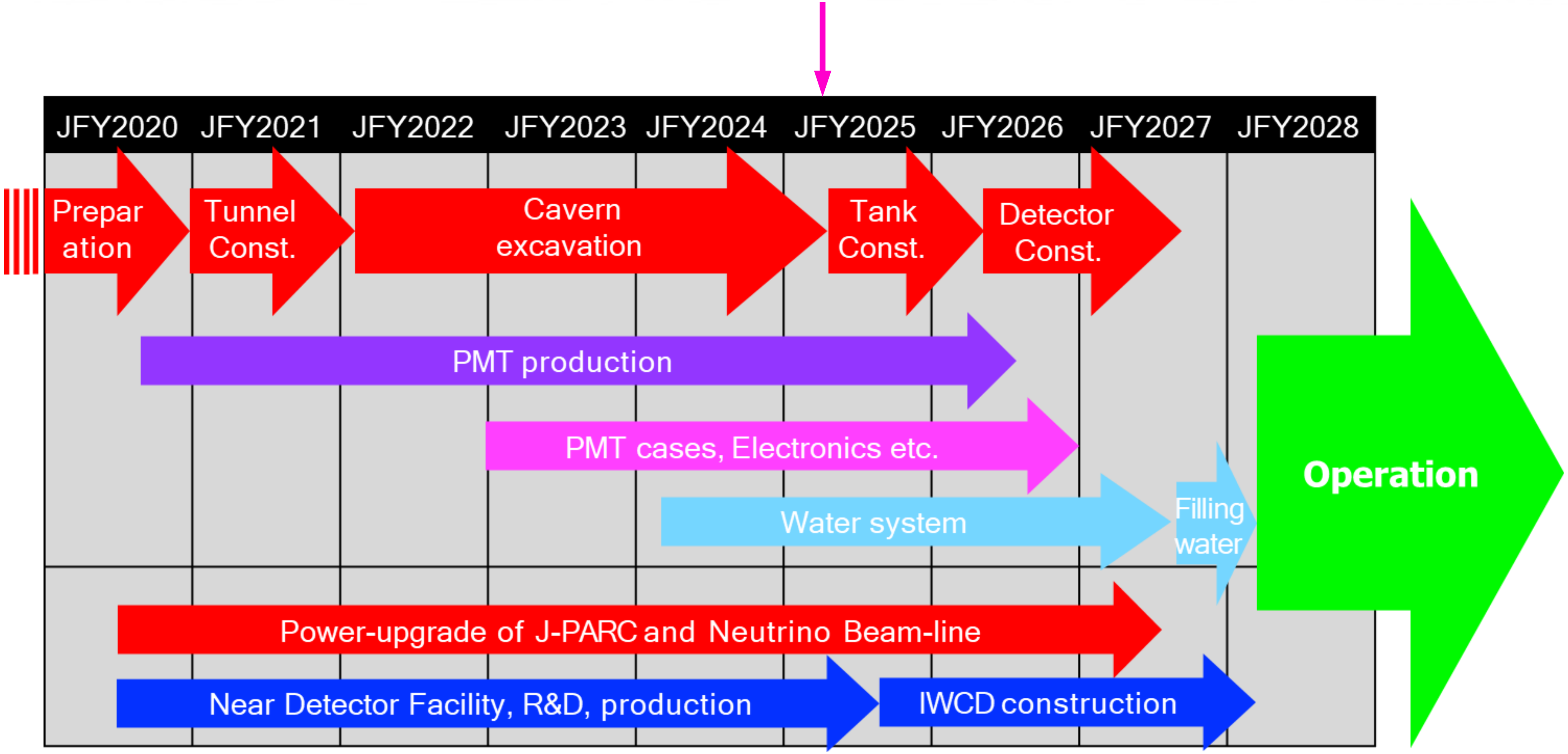
Partial lifetimes limits
(90% C.L., 10 y exposure)

- $6 \cdot 10^{34}$ years for $p \to e^+ \pi^0$
- $2 \cdot 10^{34}$ years for $p \to \bar{\nu} K^+$
- basically one order of magnitude improvement for many other modes

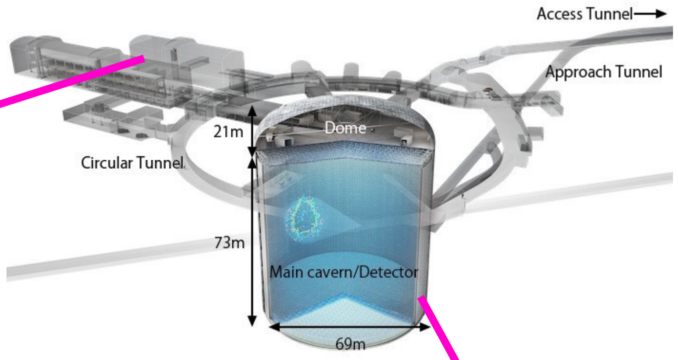
Expected 90% C.L. limits

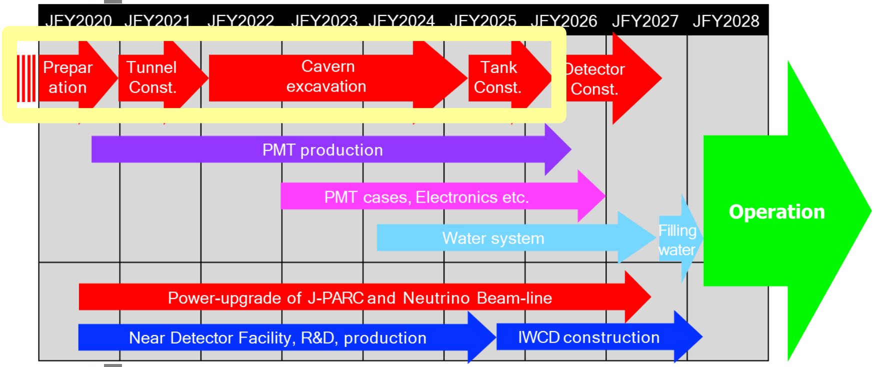


Construction schedule



Tunnels and cavern completed

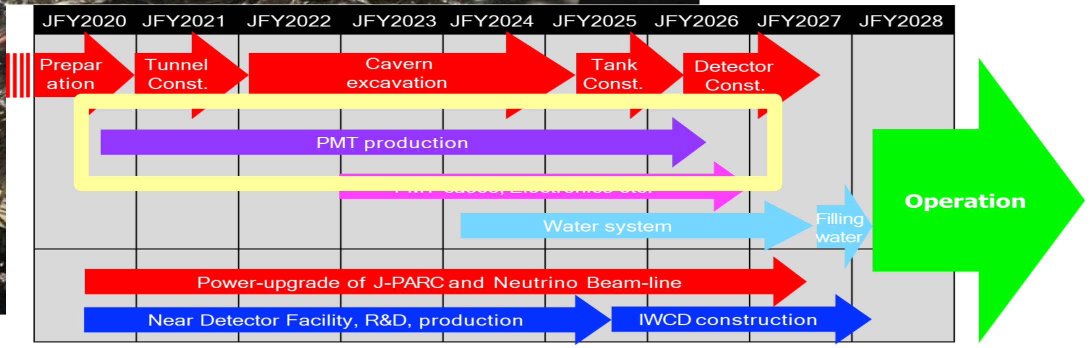




Construction phase extended by 6 months due to the changes of the structure of the detector top

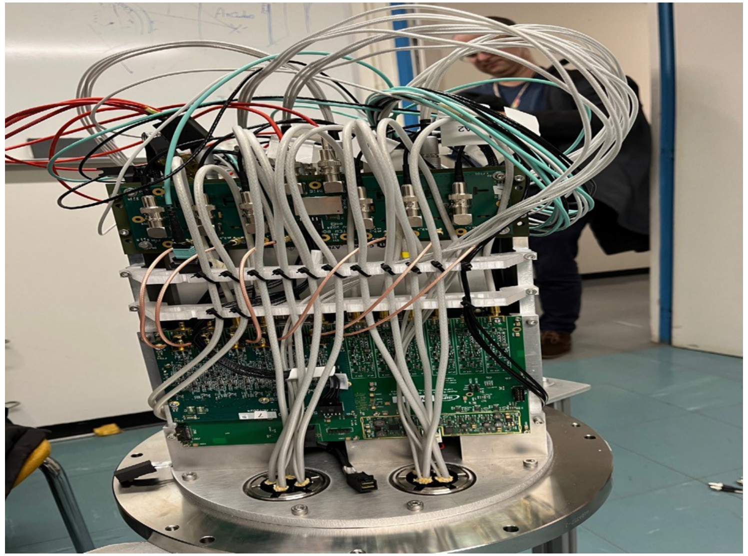
Photodetectors

- mass production of 20" PMTs
  - ~12 000 PMTs delivered and tested (QA, signal check, visual check – QA shifts by collaborators)
  - long term stabilities for several PMTs

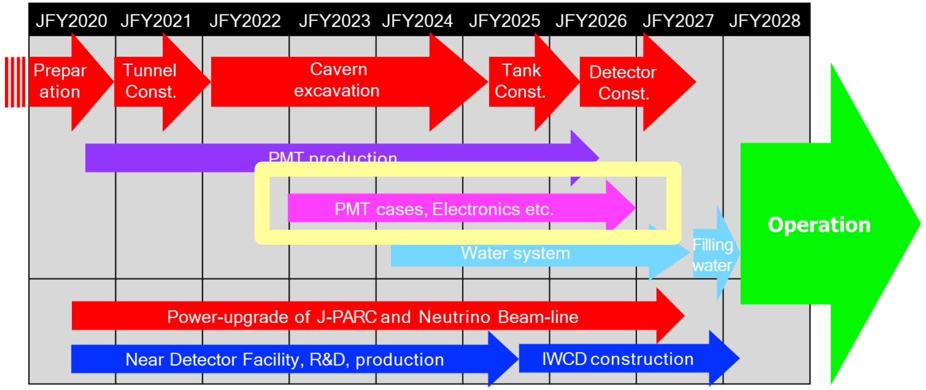


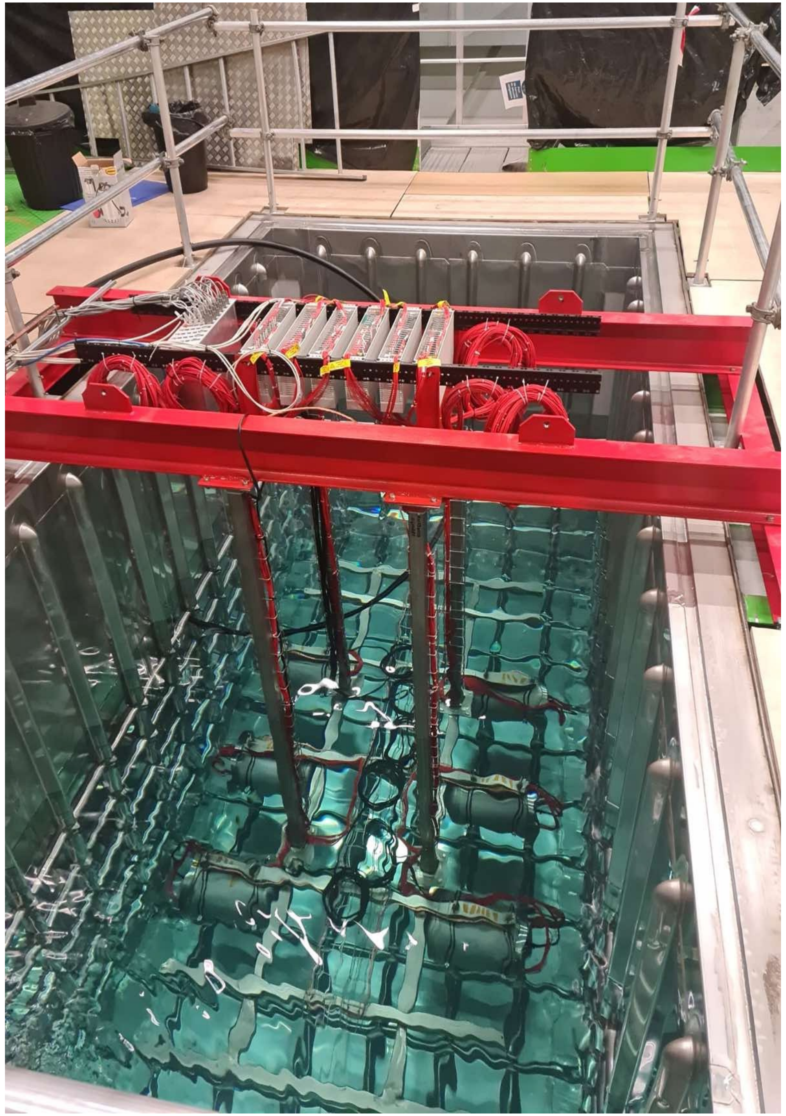
Tests of underwater electronics

- 2 main test sites: Kamioka and CERN



CERN electronics prototype





Summary

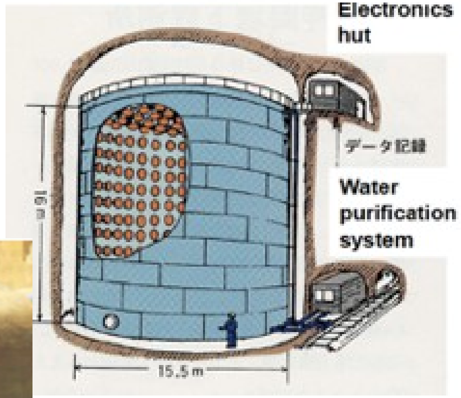
- Hyper-Kamiokande is multi-purpose project with long term, wide physics program
  - neutrino astrophysics
  - atmospheric neutrinos
  - sensitivity to nucleon lifetime up to 10^{35} years
  - high sensitivity to CP violation and other oscillation measurements
    → next talk by C. Dalmazzone
- preparations (construction, tests) ongoing
  → data taking in 2028

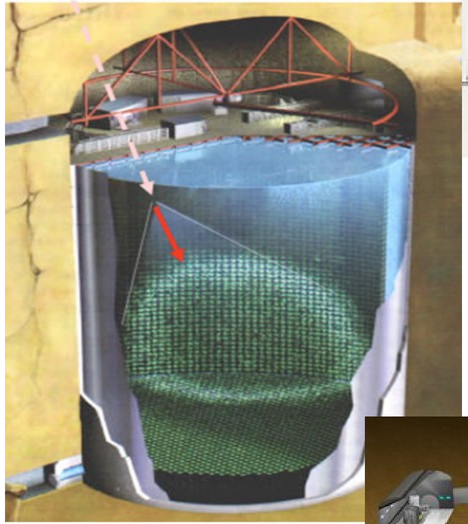
www.youtube.com/watch?v=SrQlqsSHOtM

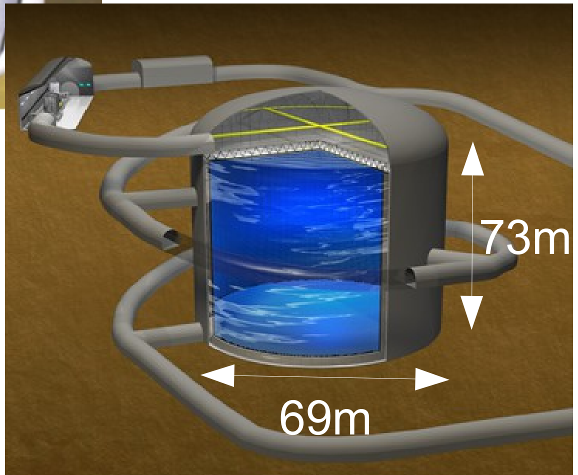
Backup slides

Water Cherenkov detectors in Japan

- **Kamiokande** 4.5 (0.68) kton
  (1983-1996) PMT coverage 20%
  - neutrinos from SN1987a, deficit of atmospheric neutrinos
- **Super-Kamiokande** 50 (22.5) kton
  (1996-) PMT coverage 40%
  - oscillations of solar and atmospheric neutrinos
  - world leading limit on proton lifetime
  - ν_e appearance
- **Hyper-Kamiokande** 258 (187) kton
  (~2027-) PMT coverage 20%
  - proto-collaboration formed January 2015, construction started 2020

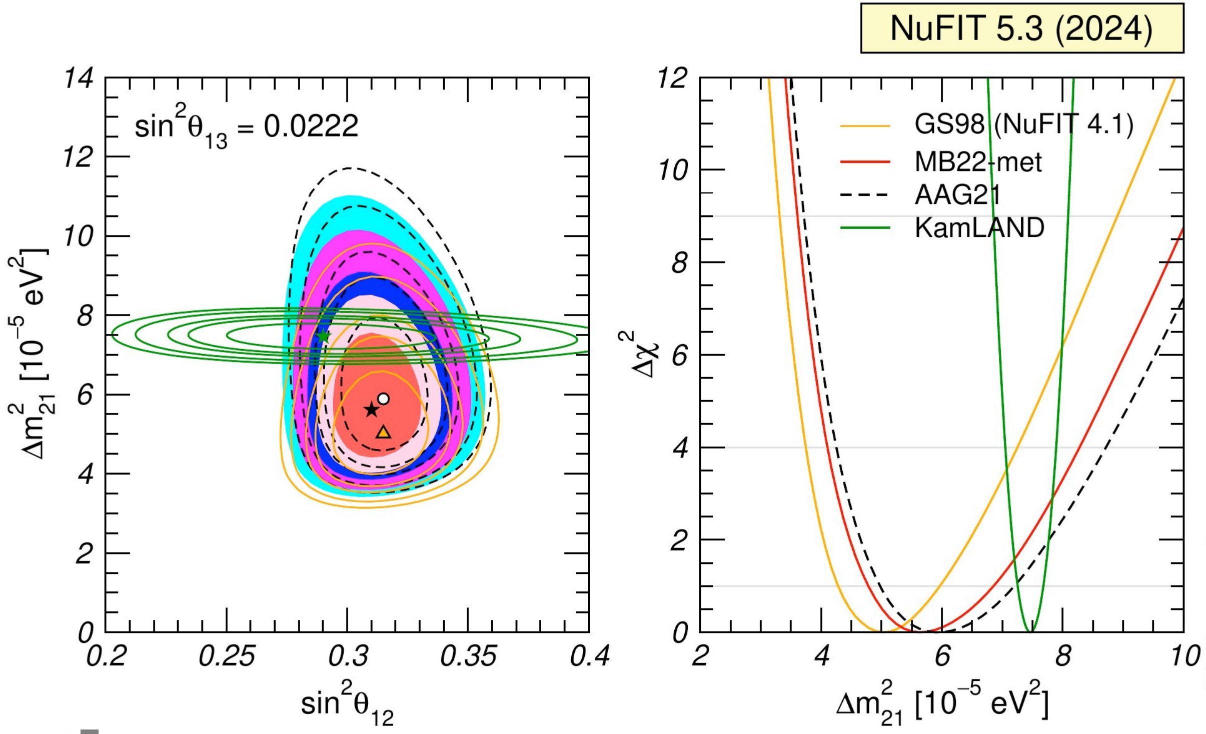




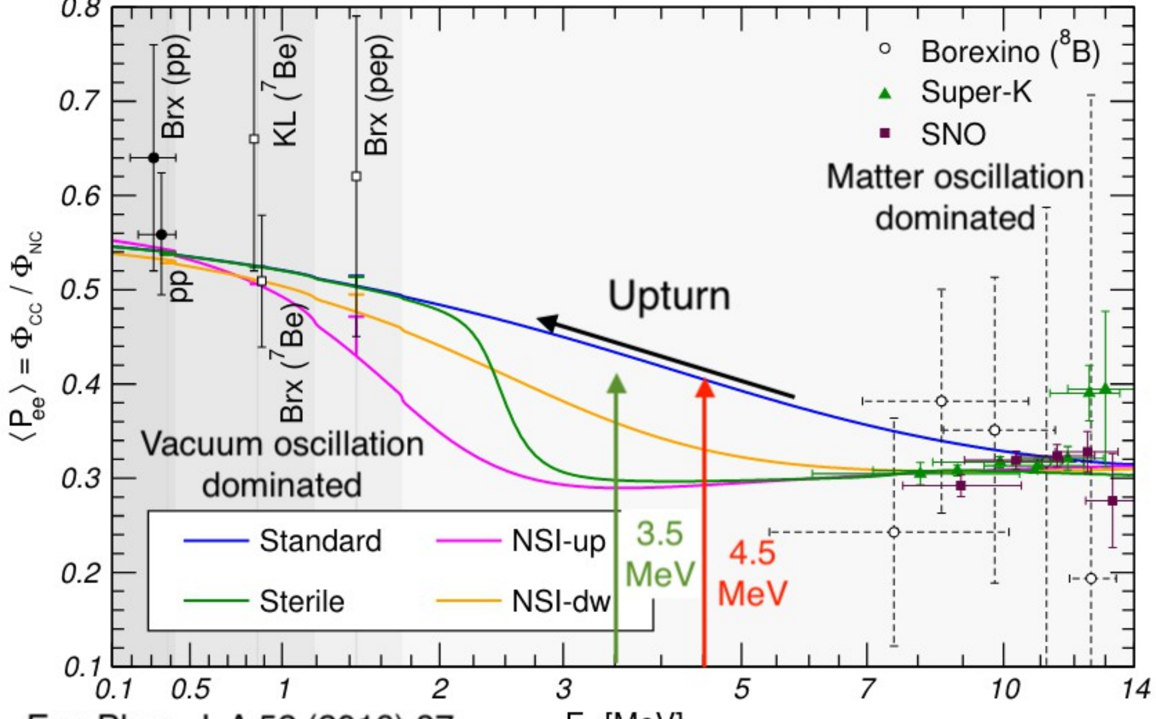


Solar neutrinos

- tension with KamLAND



Upturn region



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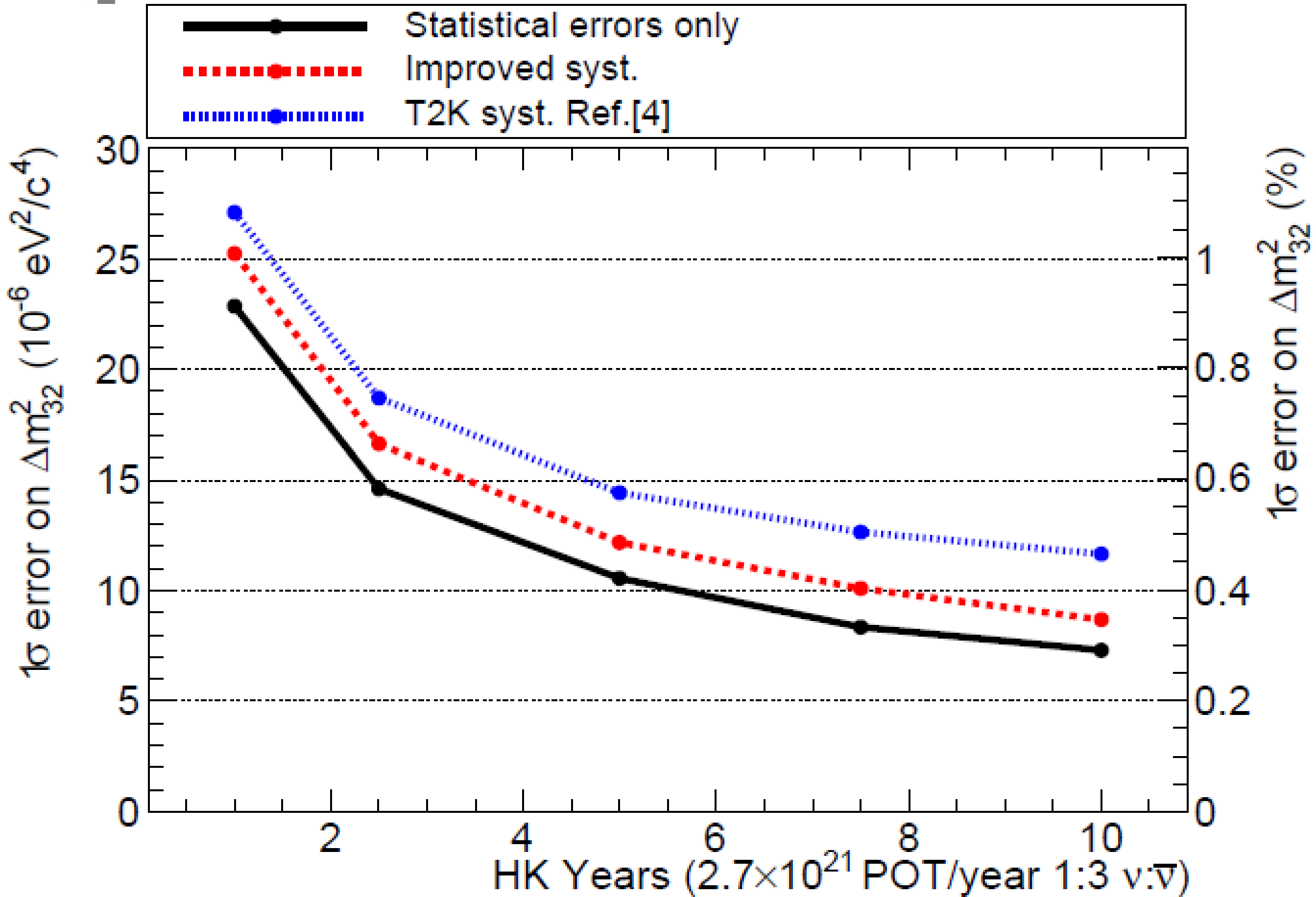
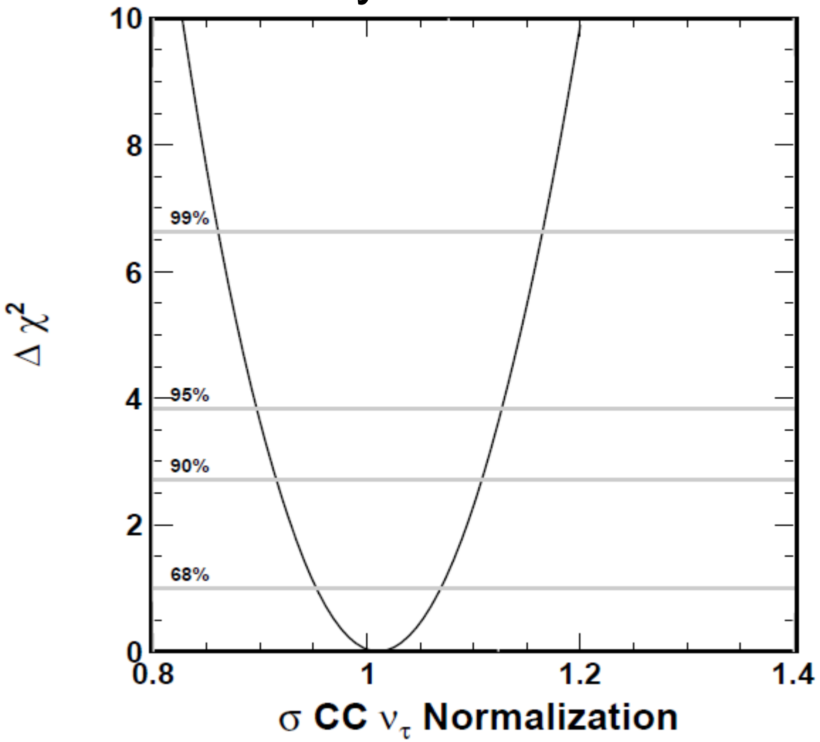
Other sensitivities

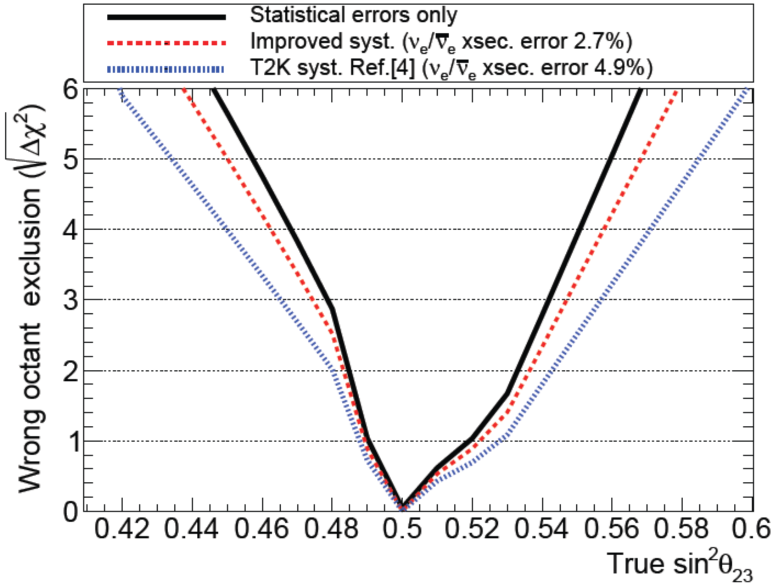
1σ error on Δm^2_{32}
(beam neutrinos)

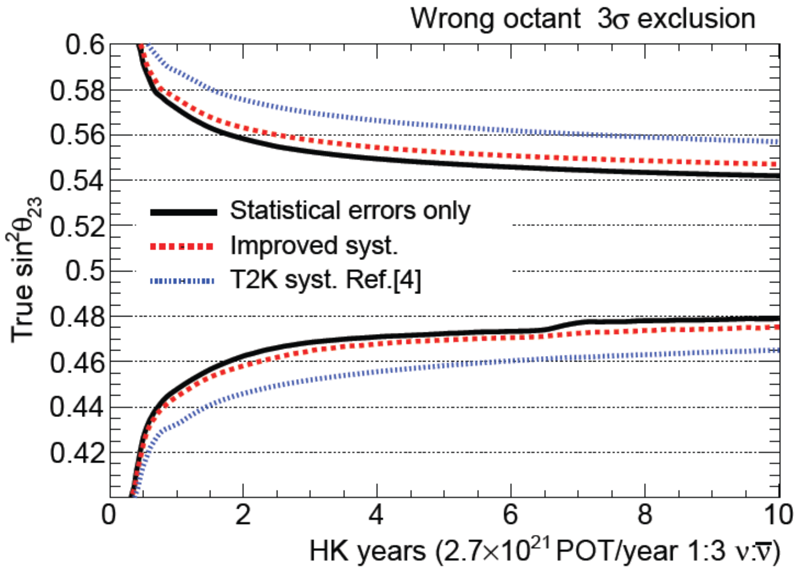


Tau appearance
(atm. neutrinos)
5.6 Mton exposure
= 30 years



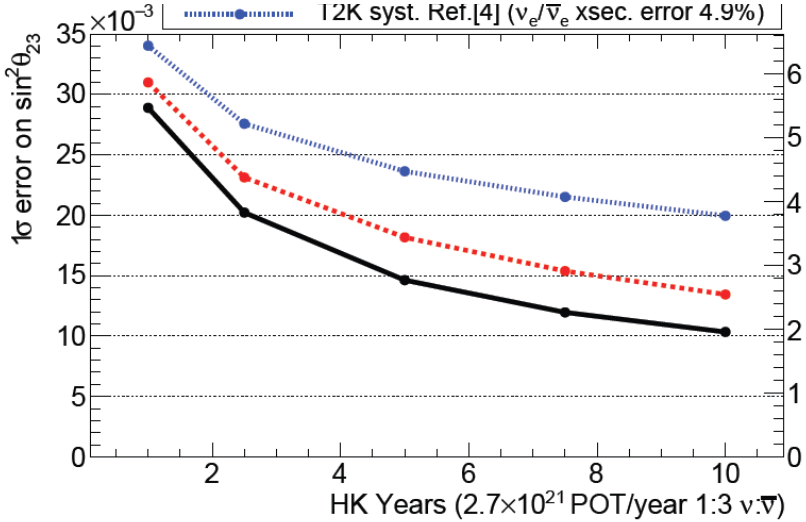
$\sin^2\theta_{23}$ (beam)

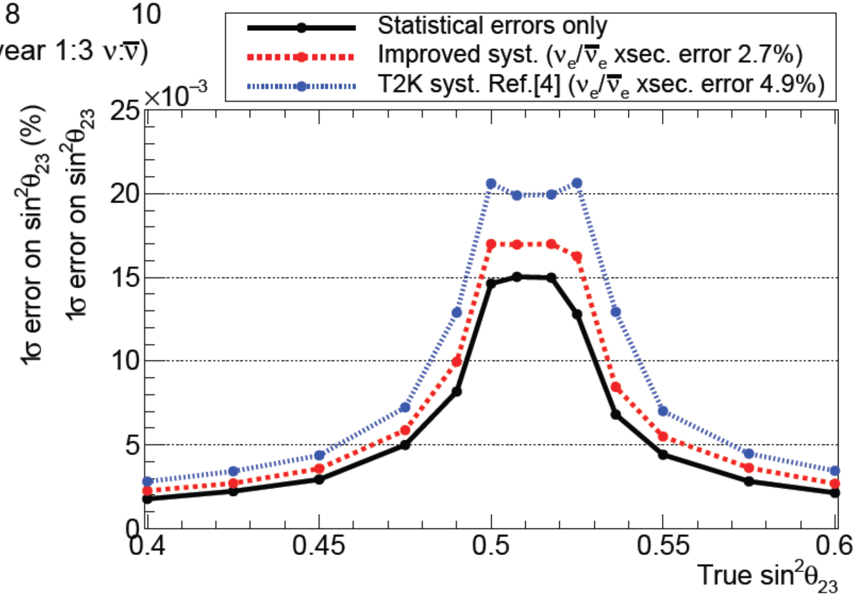




resolution between 2% and 0.4% can be reached

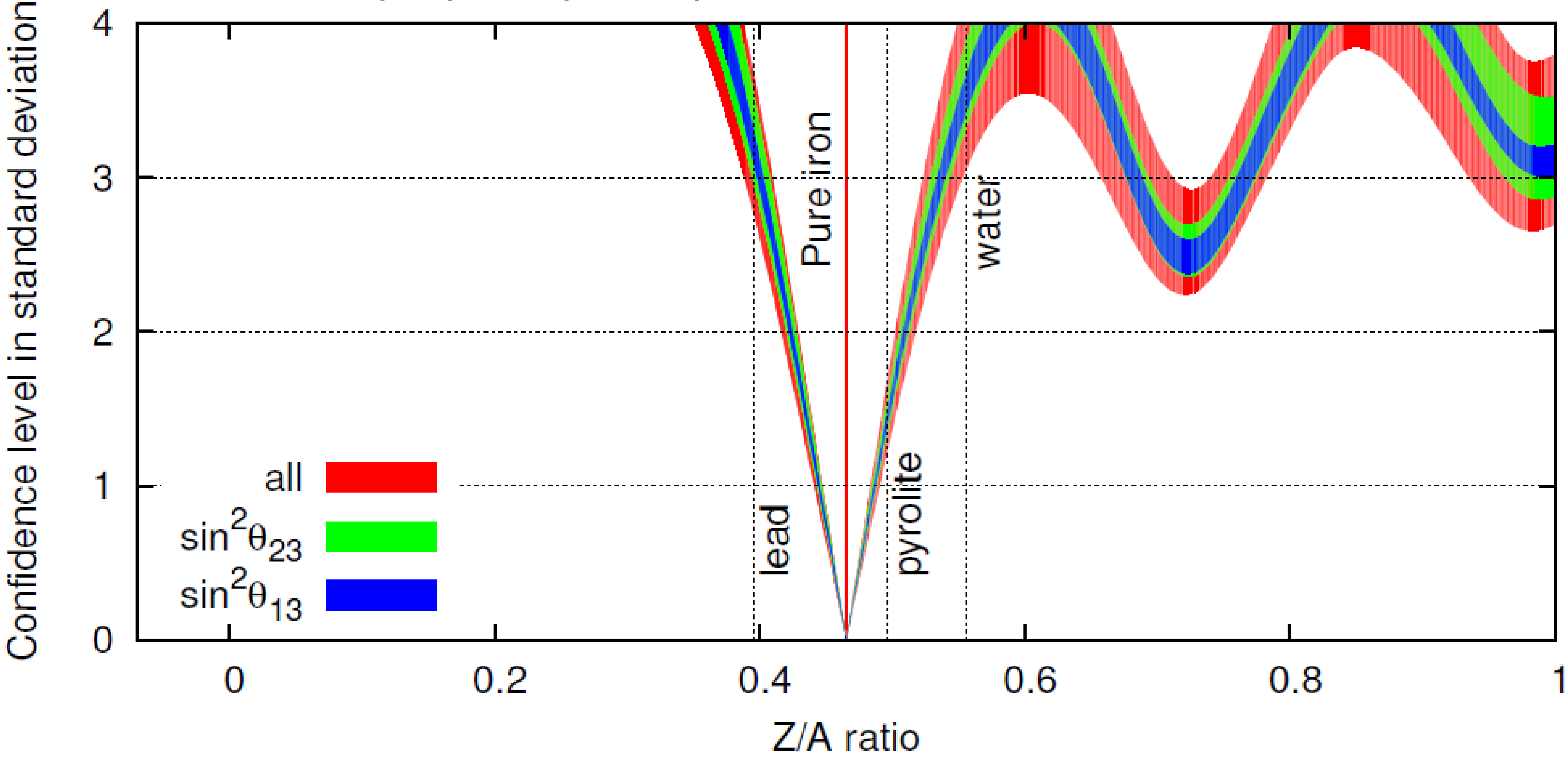
for 10 years of data taking





Chemical composition of Earth's Outer Core

Exposure 10 Mton·yr (~50 years)



Some extreme cases (water or lead) can be excluded at 3σ level.