Prospects of the Hyper-Kamiokande project

Yasuhiro Nakajima (ICRR, the University of Tokyo)
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“Three Neutrinos and Beyond”

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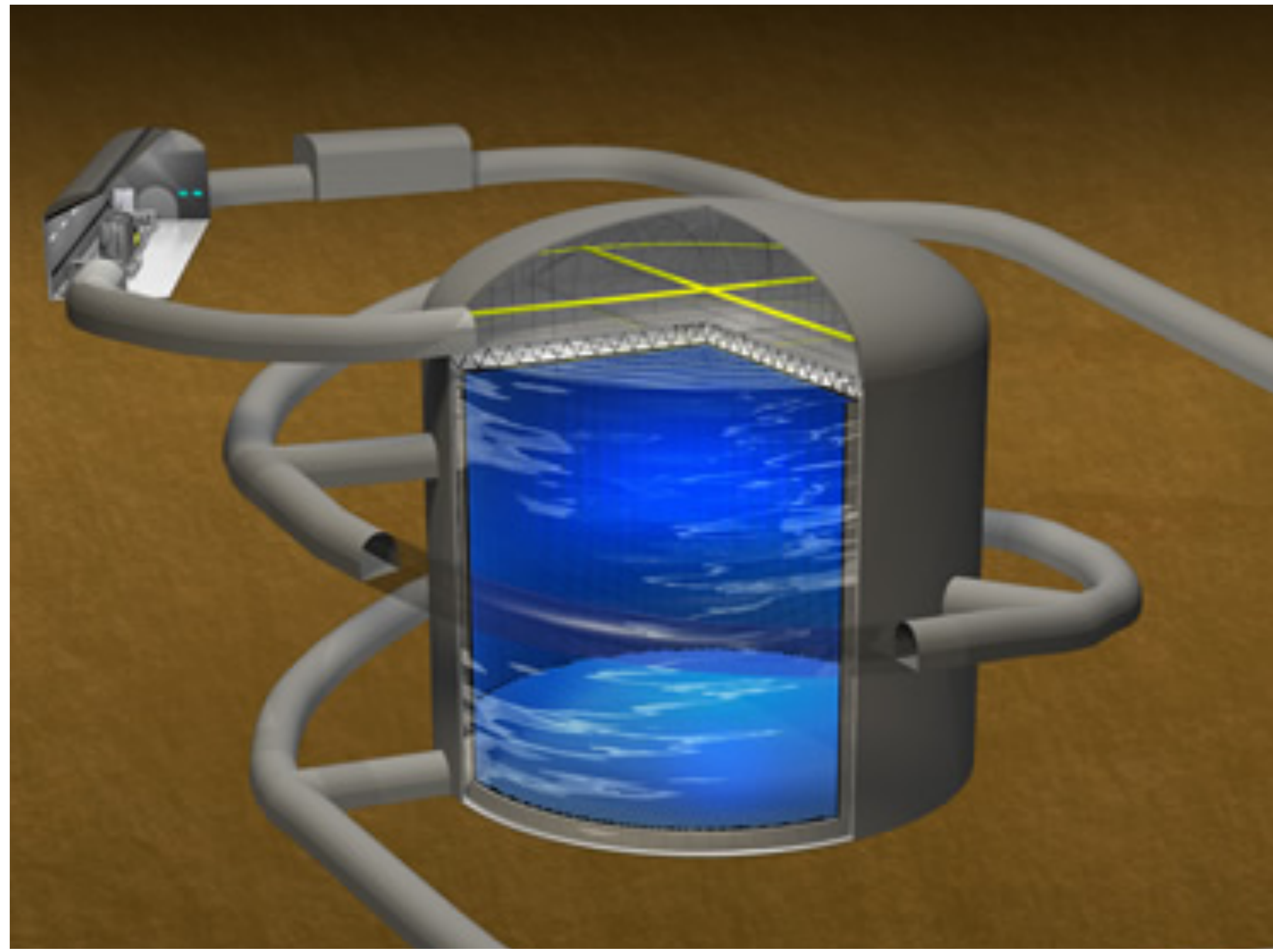
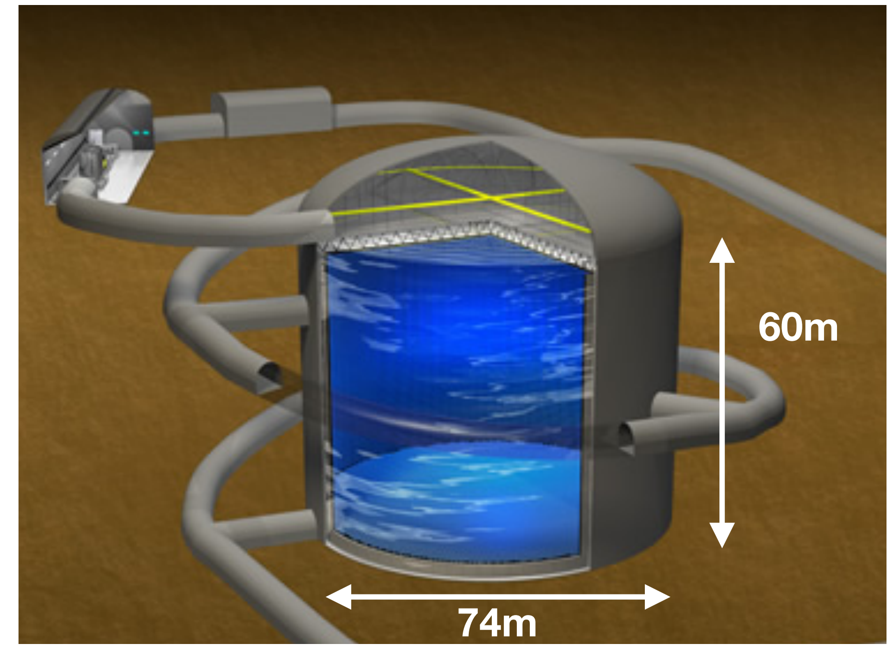
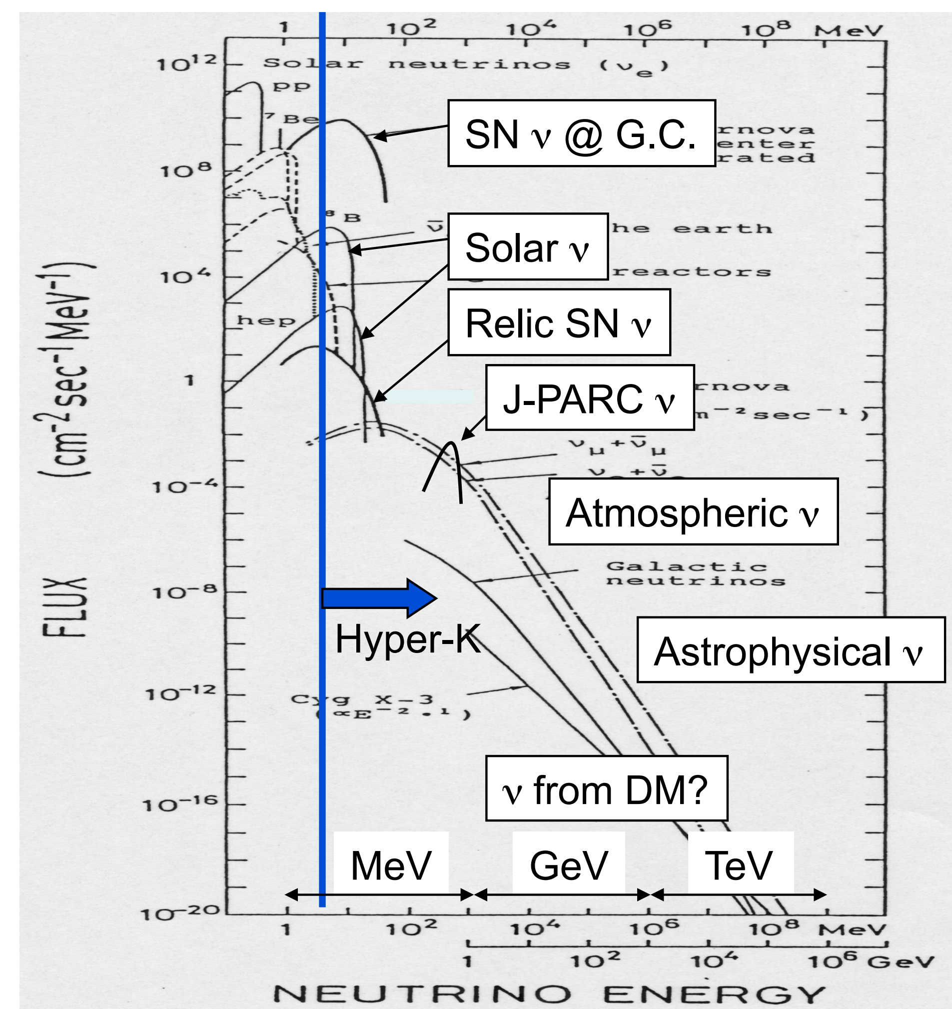


The Hyper-Kamiokande Project

- Next-generation large water Cherenkov Detector
  - 190 kton fiducial volume: ~x8 of Super-K
  - 40% photo-coverage with high-efficiency 20” PMTs
- Vast range of physics programs:
  - Neutrino oscillation study with > 1.3 MW J-PARC beam and upgraded near and intermediate detector complex from T2K
  - Atmospheric, solar and astrophysical neutrino studies
  - Search for nucleon decays





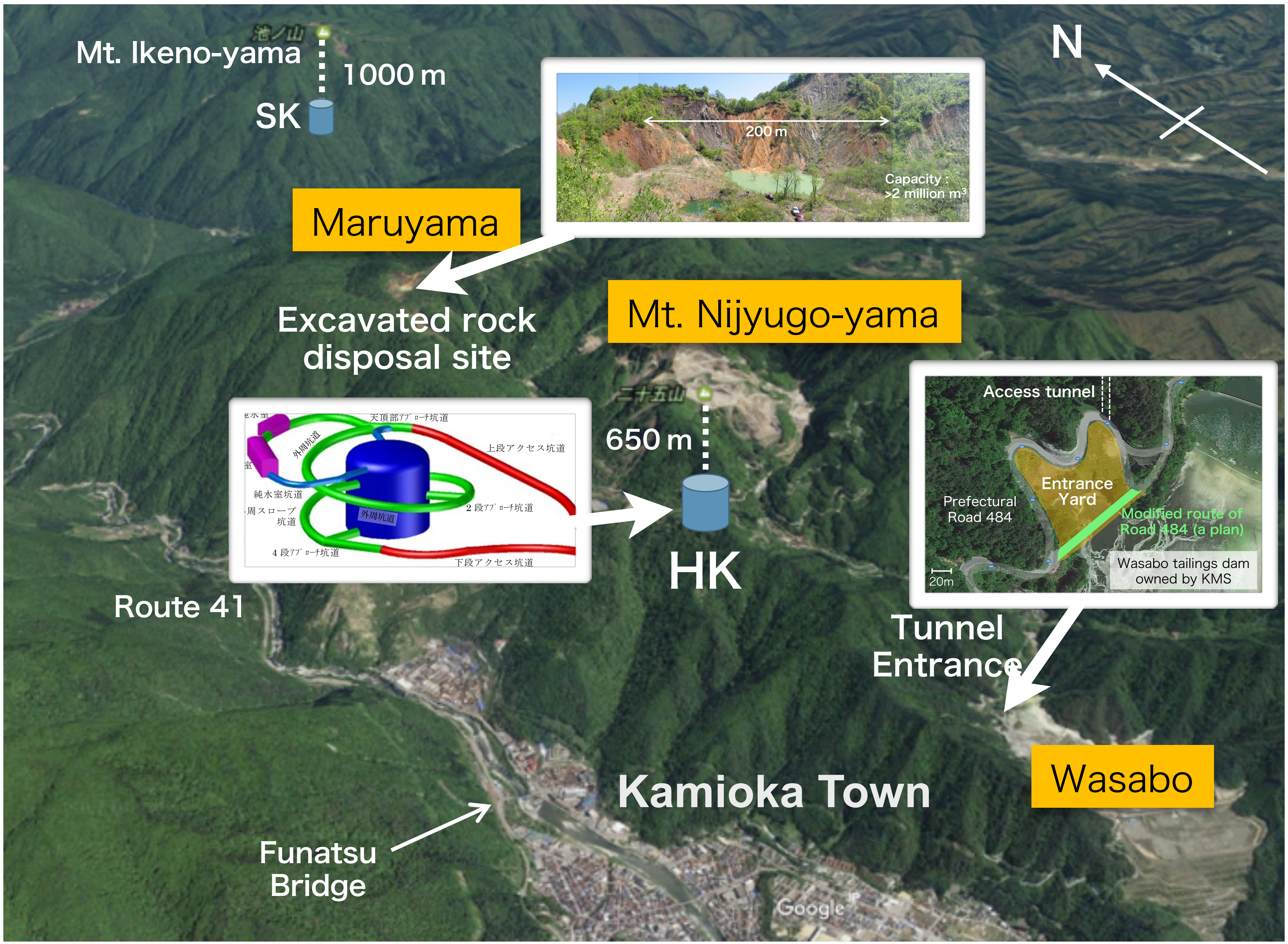
Details in Hyper-K Design Report (arXiv: 1805.04163)

International Hyper-K Proto-Collaboration

15 + 2 countries, ~80 institutes, ~300 members

Candidate site

8 km south of Super-K
650 m rock overburden

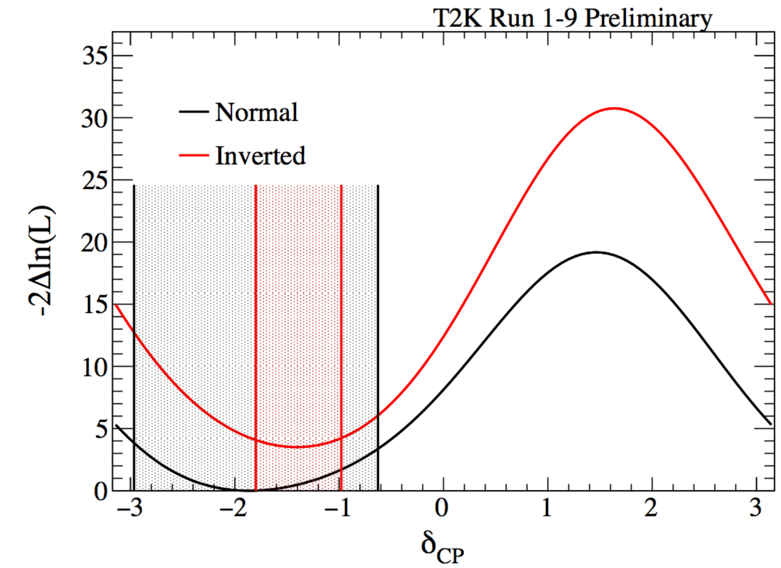


Physics targets of HK

- Study unresolved property of neutrinos
    - CP violation in the lepton sector
    - Determination of mass ordering, θ_{23} octant
    - Precision test of the tension of Δm^2_{21} between reactor and solar neutrino data
- Observation of astrophysical neutrinos w/ much extended range
    - Precise measurement of supernova (relic) neutrinos
- Search for proton decay

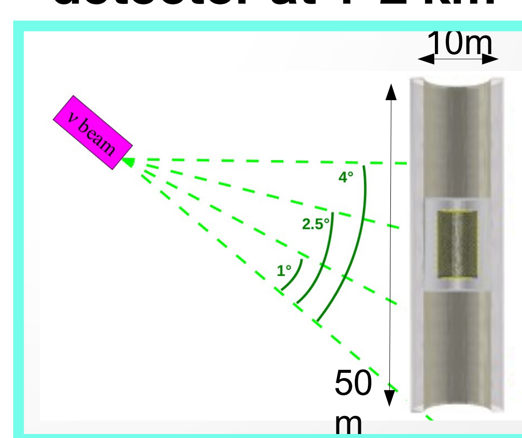
HK can study all of those items with an order of magnitude better sensitivity than currently running experiments

Accelerator neutrinos

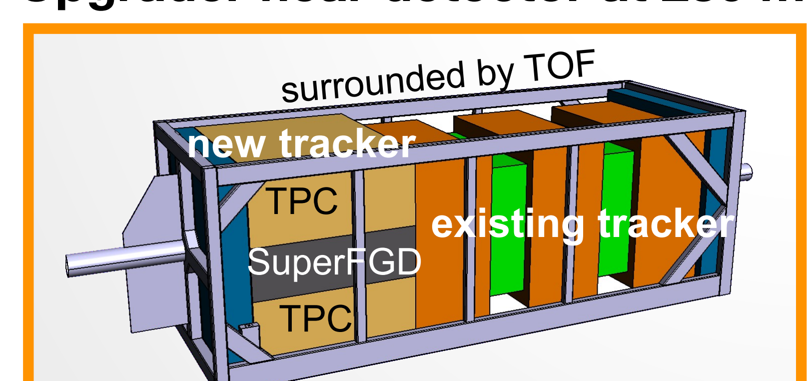


- T2K observed a hint of CP-violation
  - Current T2K statistics: 90 ν_e and 15 $\overline{\nu}_e$ candidates
- HK can study further with O(1000) $\nu_\mu \rightarrow \nu_e$ and $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ appearance events: ~3% statistical precision!
- Better control of systematics is crucial
  - Current T2K systematics: 6-7%
  - Upgraded near-detector and new intermediate detector to constrain flux+interaction systematics to <4%
- Even further study with a second detector in Korea actively considered

Intermediate detector at 1-2 km



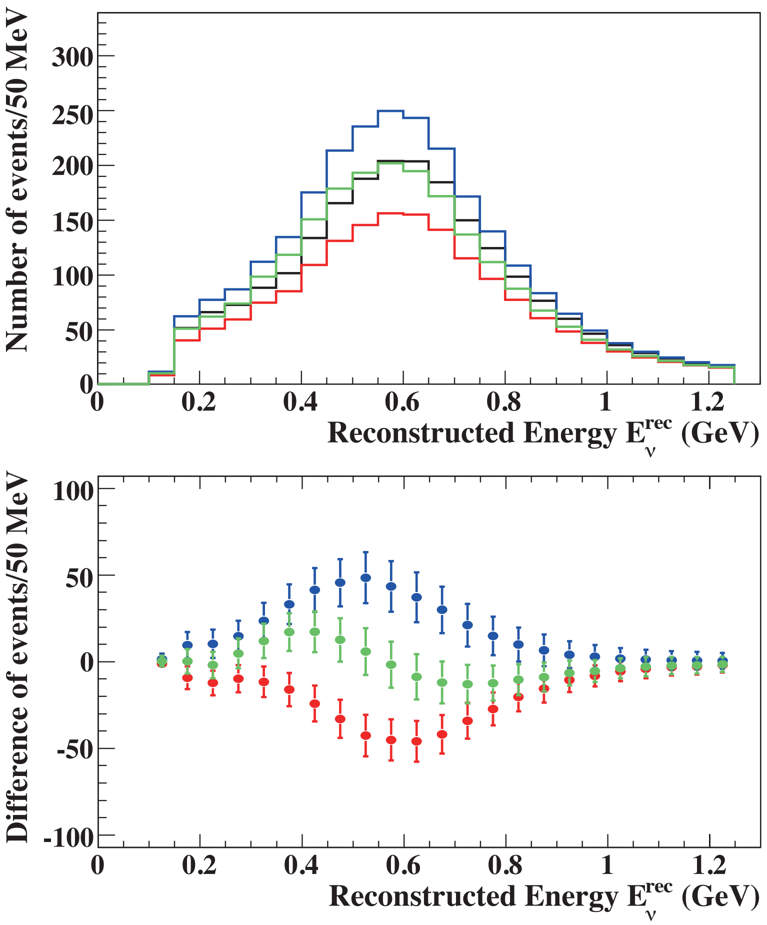
Upgrader near detector at 280 m



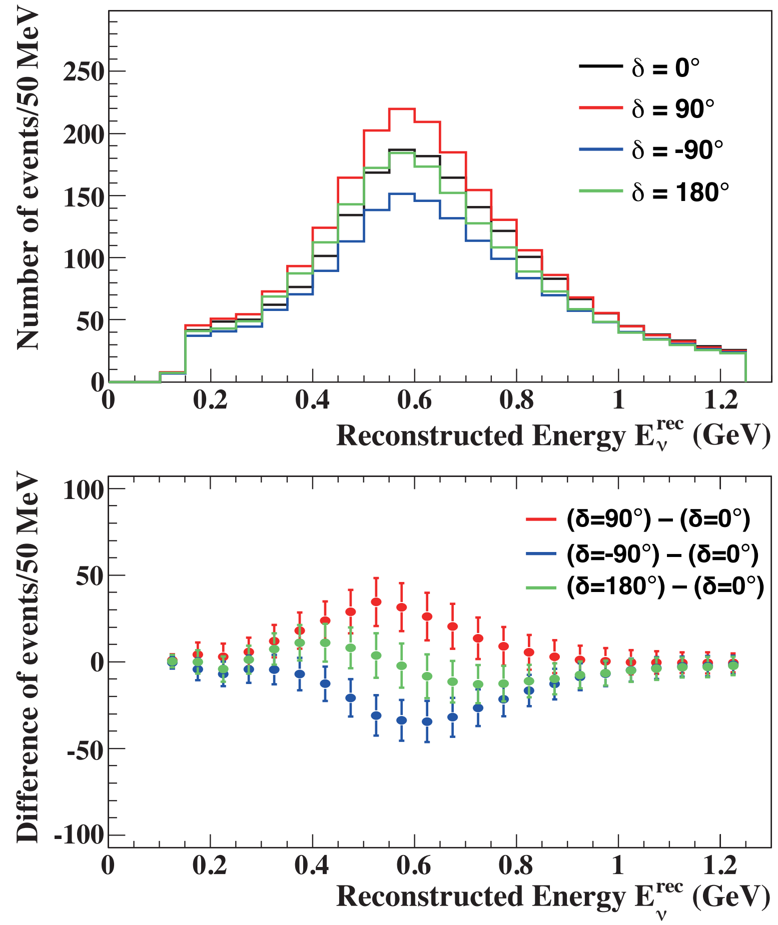
Expected signal

10 years (10yrs×1.3MW×10^{7}s), ν : νbar = 2.5yrs : 7.5yrs

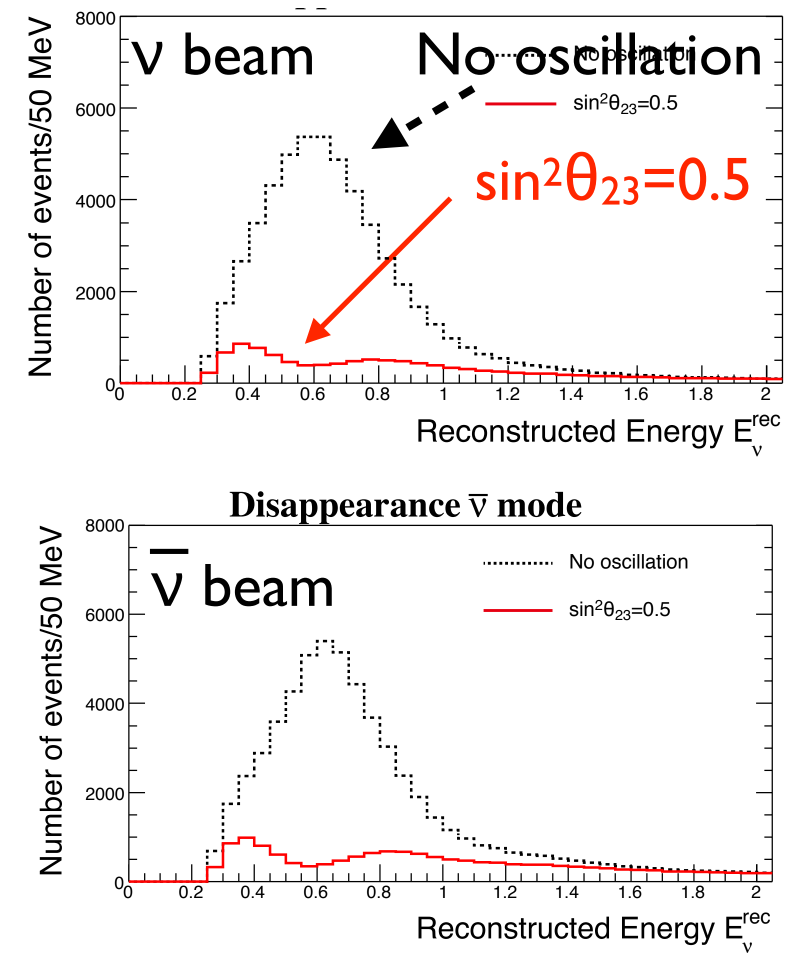
ν_e appearance



$\overline{\nu}_e$ appearance



ν_μ disappearance

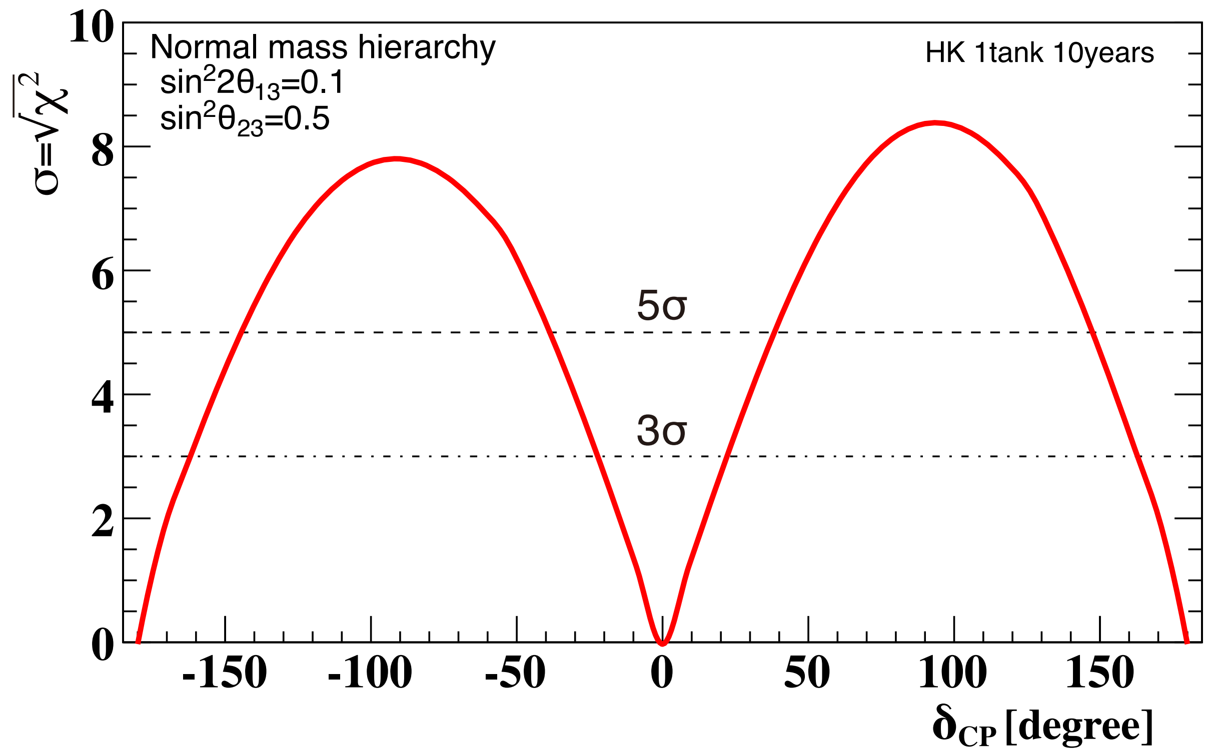


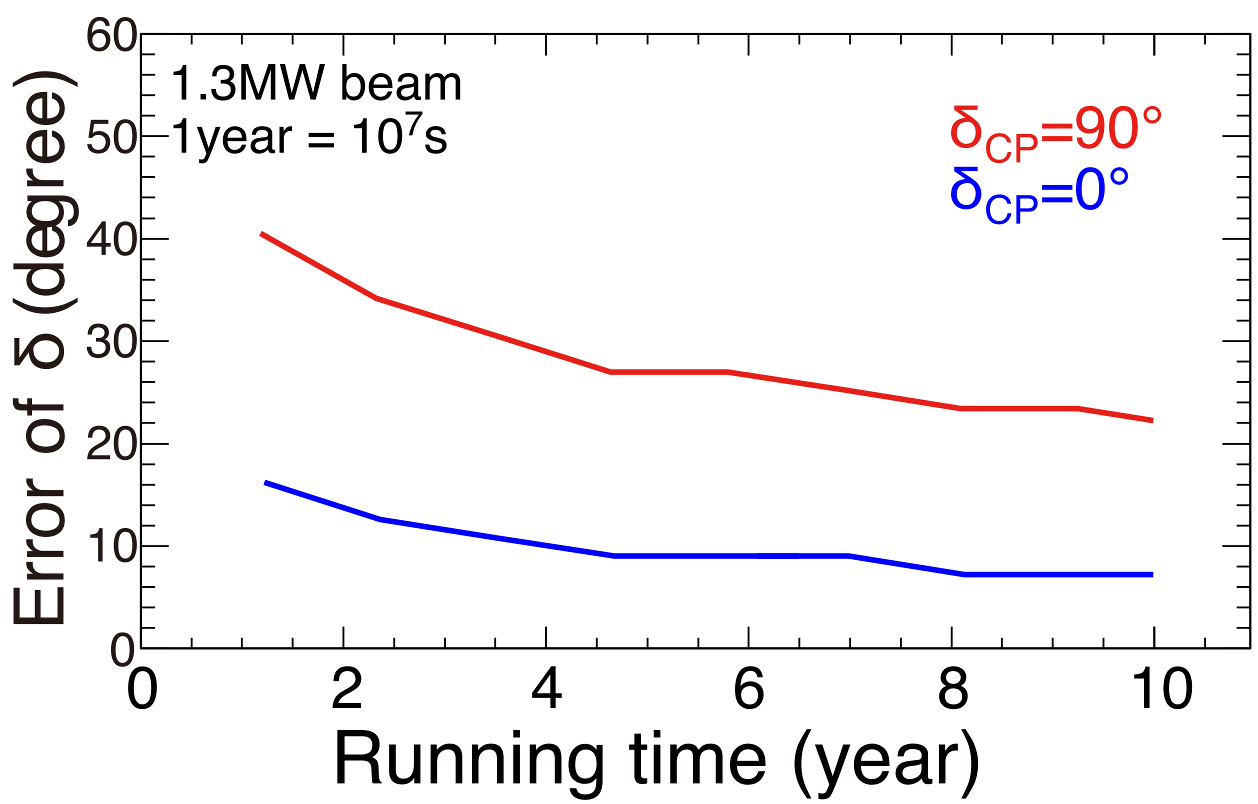
for δ=0	Signal ($\nu_\mu \to \nu_e$ CC)	Wrong sign appearance	$\nu_\mu/\overline{\nu}_\mu$ CC	beam $\nu_e/\overline{\nu}_e$ contamination	NC
ν beam	1,643	15	7	159	134
$\overline{\nu}$ beam	1,183	206	4	317	196

	$\nu_\mu+\overline{\nu}_\mu$ CCQE	ν_μCC nonQE	Others
ν beam	6,391	3175	515
$\overline{\nu}$ beam	8,798	4315	614

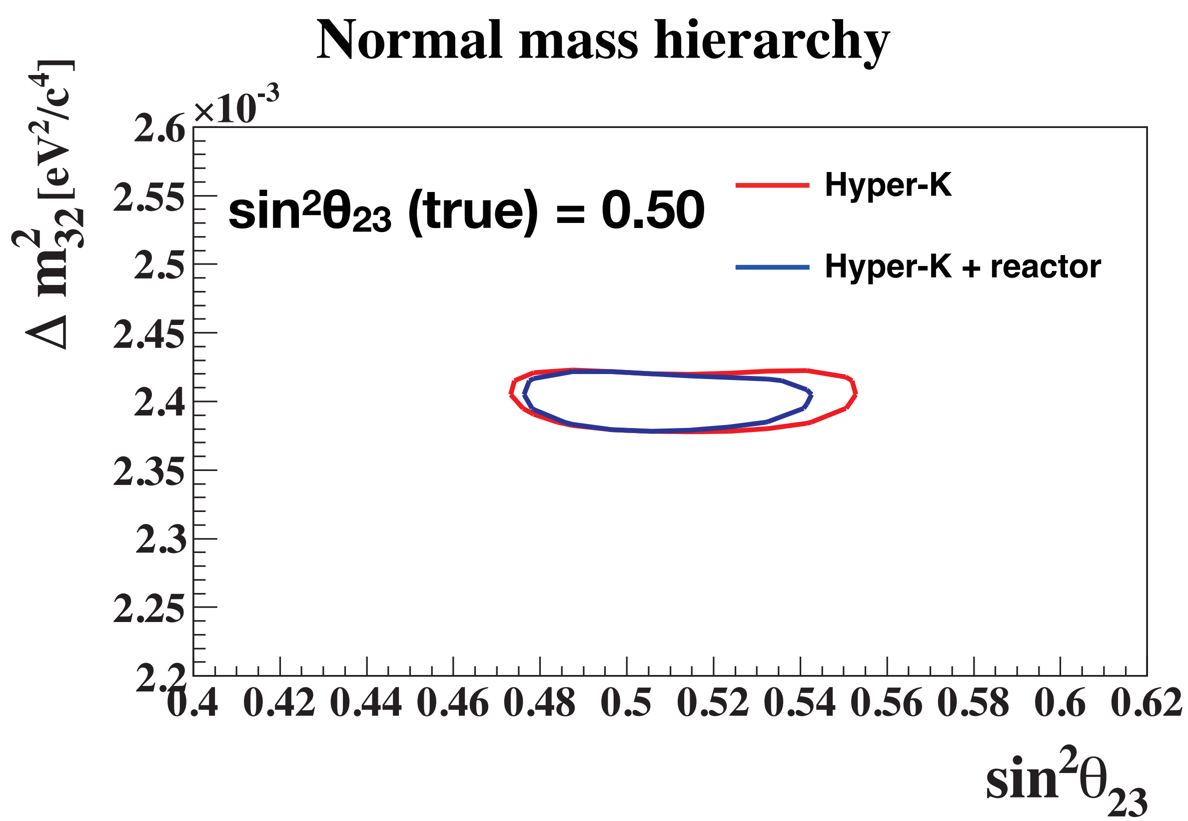
CPV sensitivity

- Exclusion of sin $\sin\delta_{CP} = 0$
  - 8σ for $\delta = -90^{o}$ (current T2K best fit)
  - ~80% coverage of δ parameter space for $>3\sigma$ discovery of CPV
- Precision measurement of δ_{CP}:
  - ~22^{o} uncertainty for $\delta = \pm 90^{o}$
  - ~7^{o} uncertainty for $\delta = 0^{o}$ or 180^{o}
- Further enhancement with combined analysis with atmospheric neutrino data

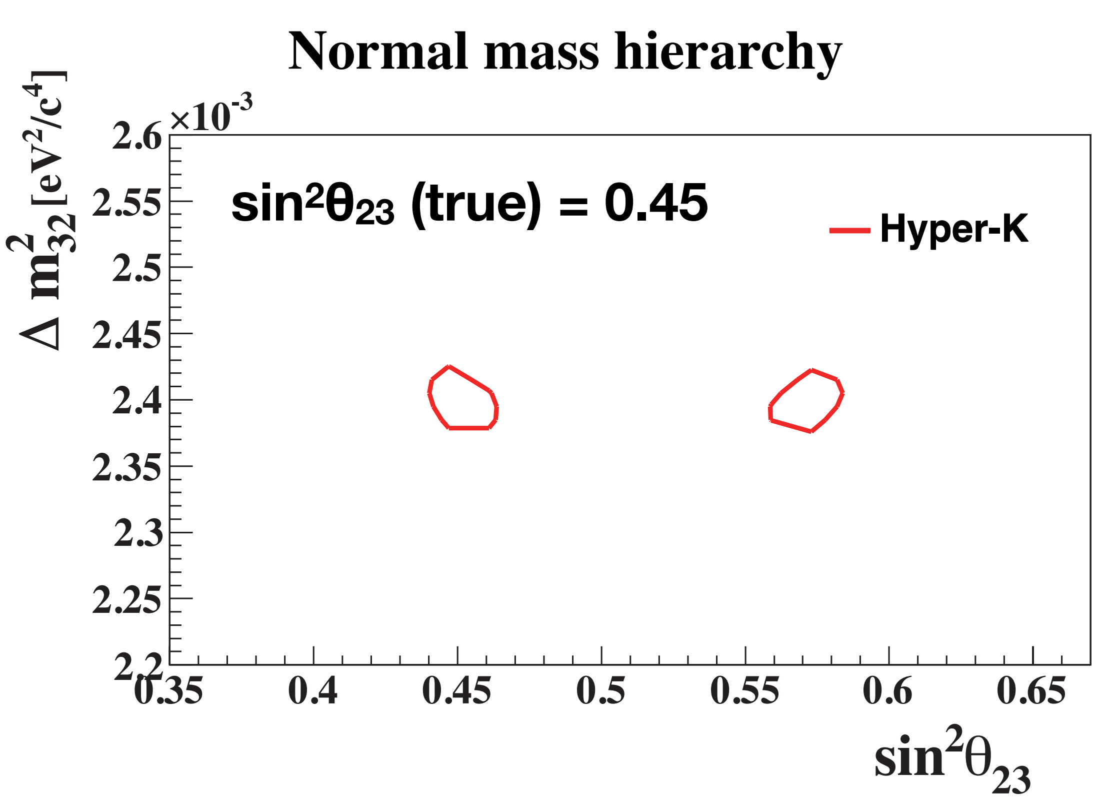


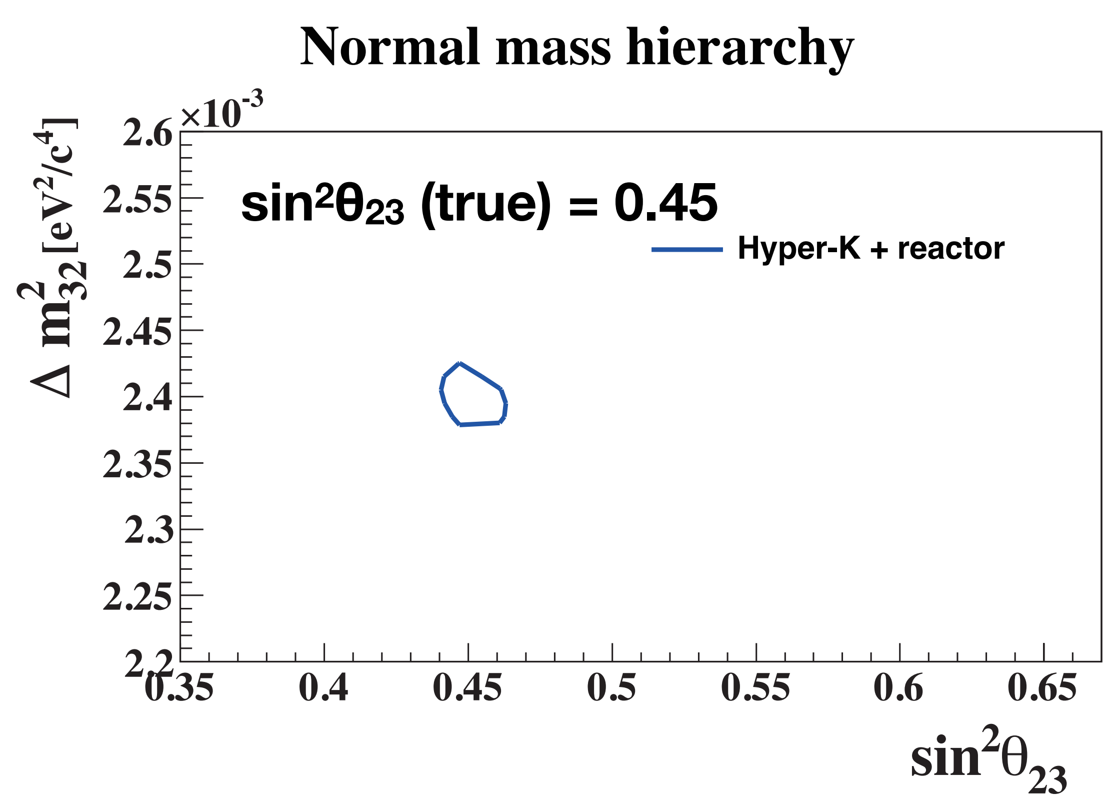


Precise measurement of Δm^2_{32} and θ_{23}

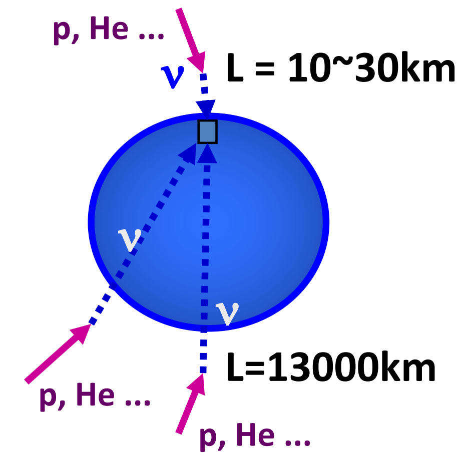


- Expected precision:
  - Δm^2_{32}: 1.5 x 10^{-5} eV^2 (0.6%)
  - $\sin^2\theta_{23}$: 0.006 (0.017) at $\sin^2\theta_{23}$ = 0.45 (0.50)
- Reactor constraints help resolving θ_{23} octant

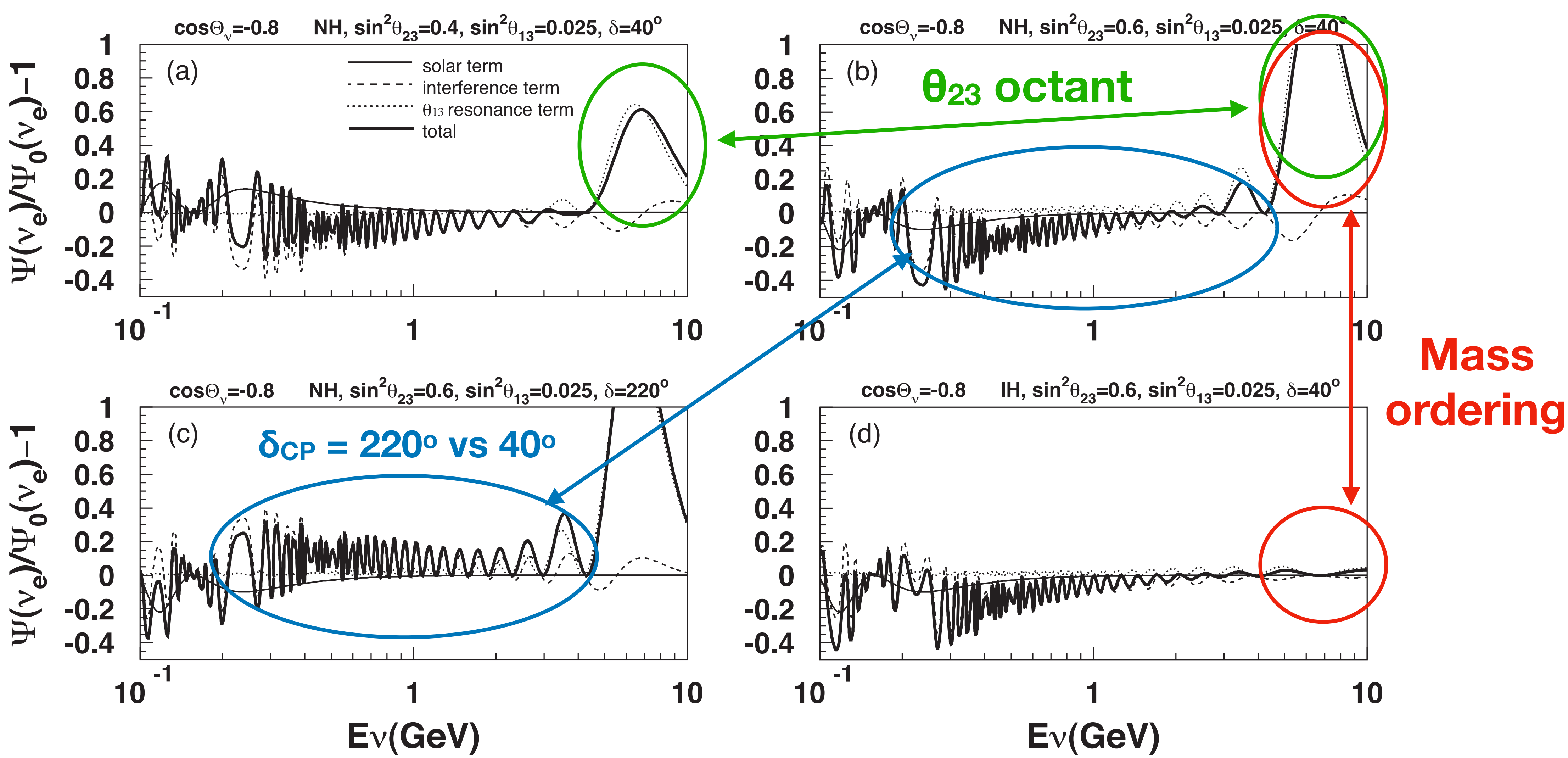




Atmospheric neutrinos

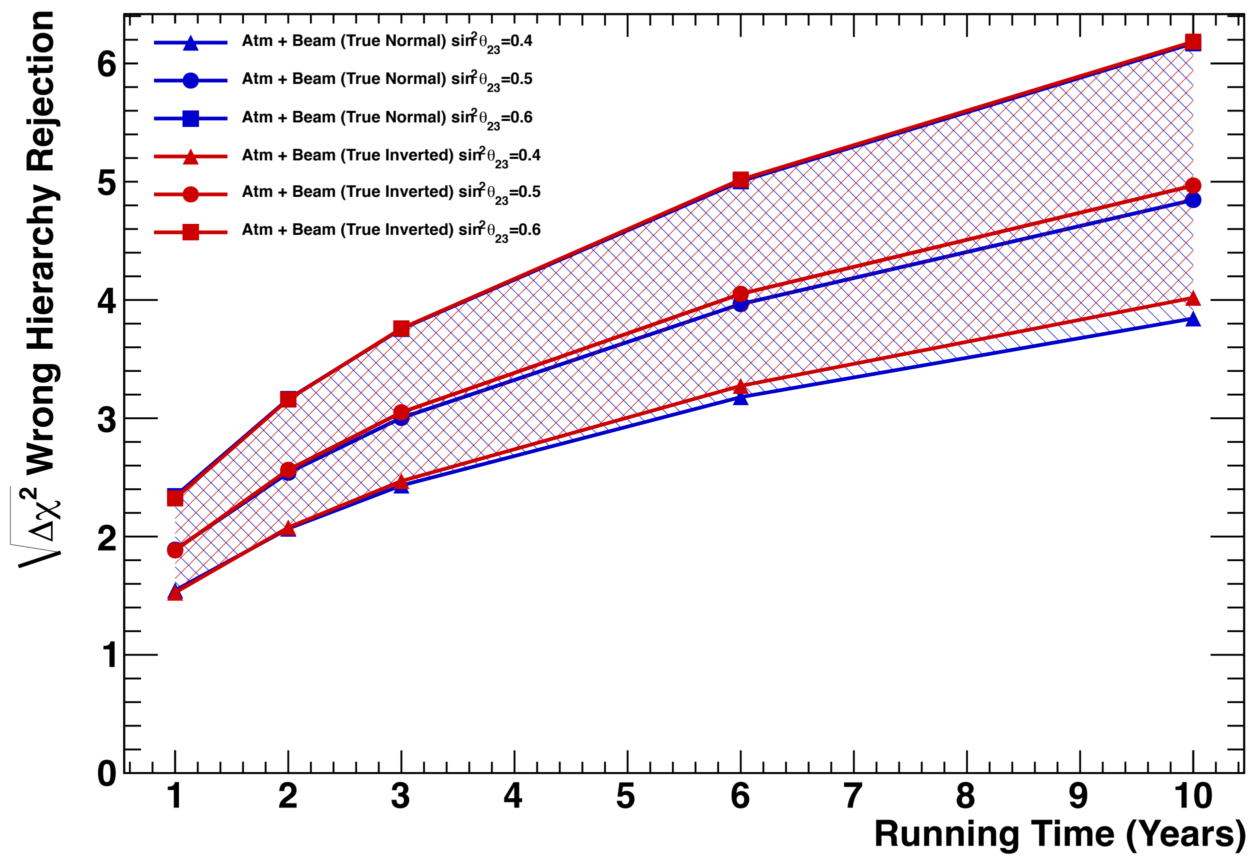


- Unique source to study neutrino oscillation with:
  - Wide energy range: ~100 MeV to ~10 GeV
  - Large variety of baseline (10 km to 13000 km) and matter effect
- Sensitive to **Mass ordering**, **θ_{23} octant** and **δ_{CP}**

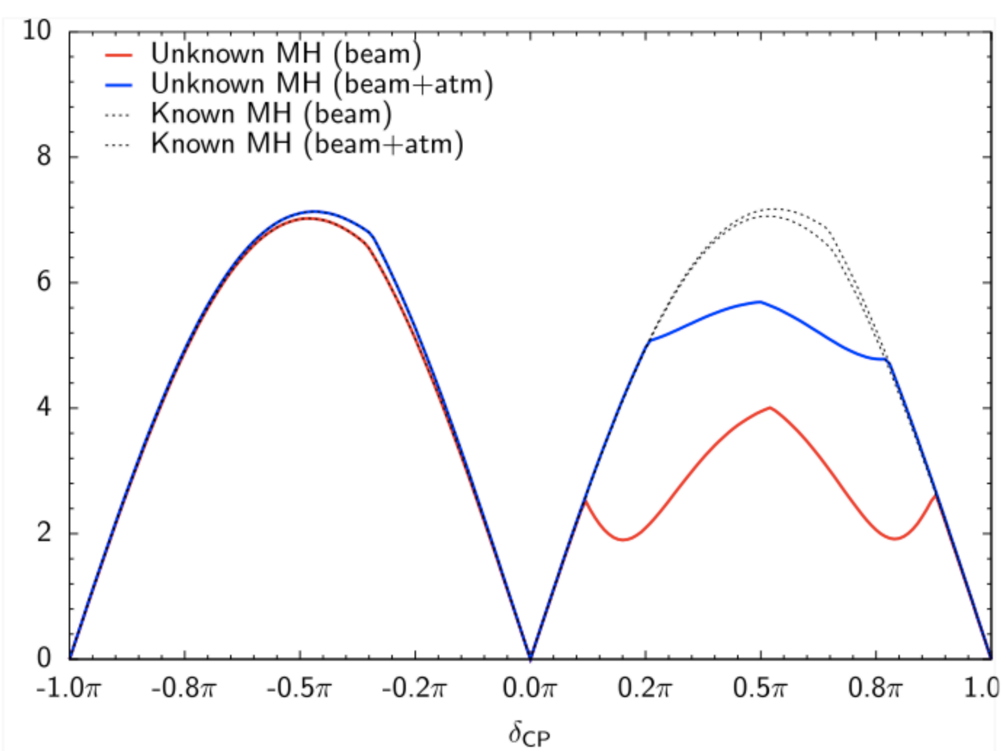


Beam + atmospheric combination

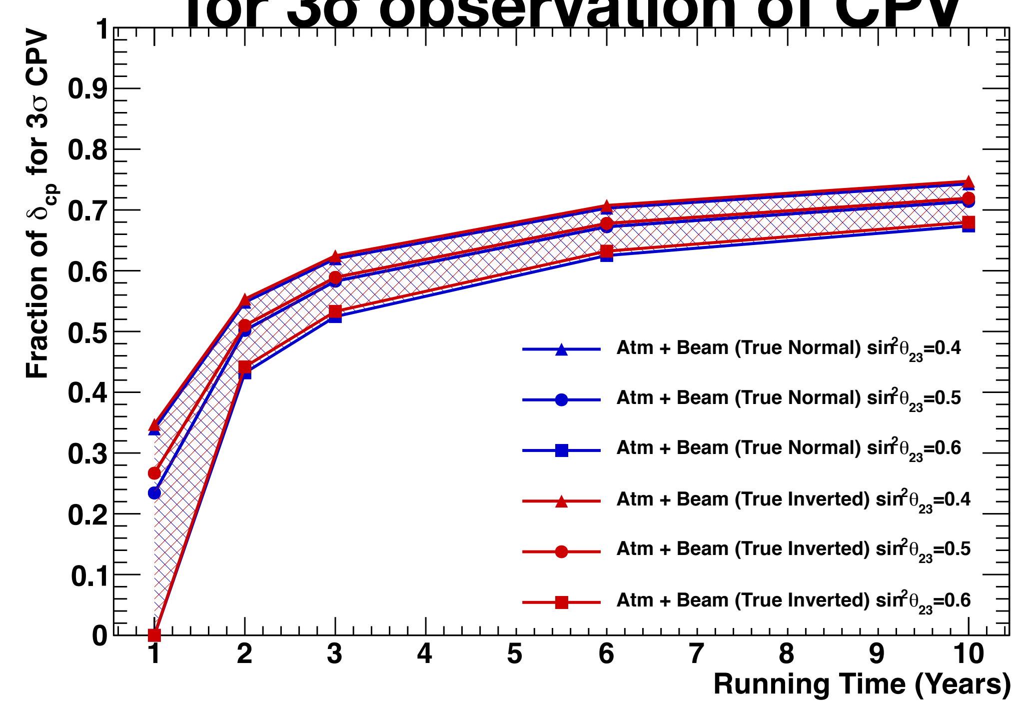
- Combination of atmospheric and beam data can provide strong constraints to mass hierarchy (MH)
- Can determine the MH at 3σ-5σ level after 6 years with HK-only data.
- Significant increase of CP-violation sensitivity even without prior knowledge of MH



Significance to exclude δ_{CP} = 0



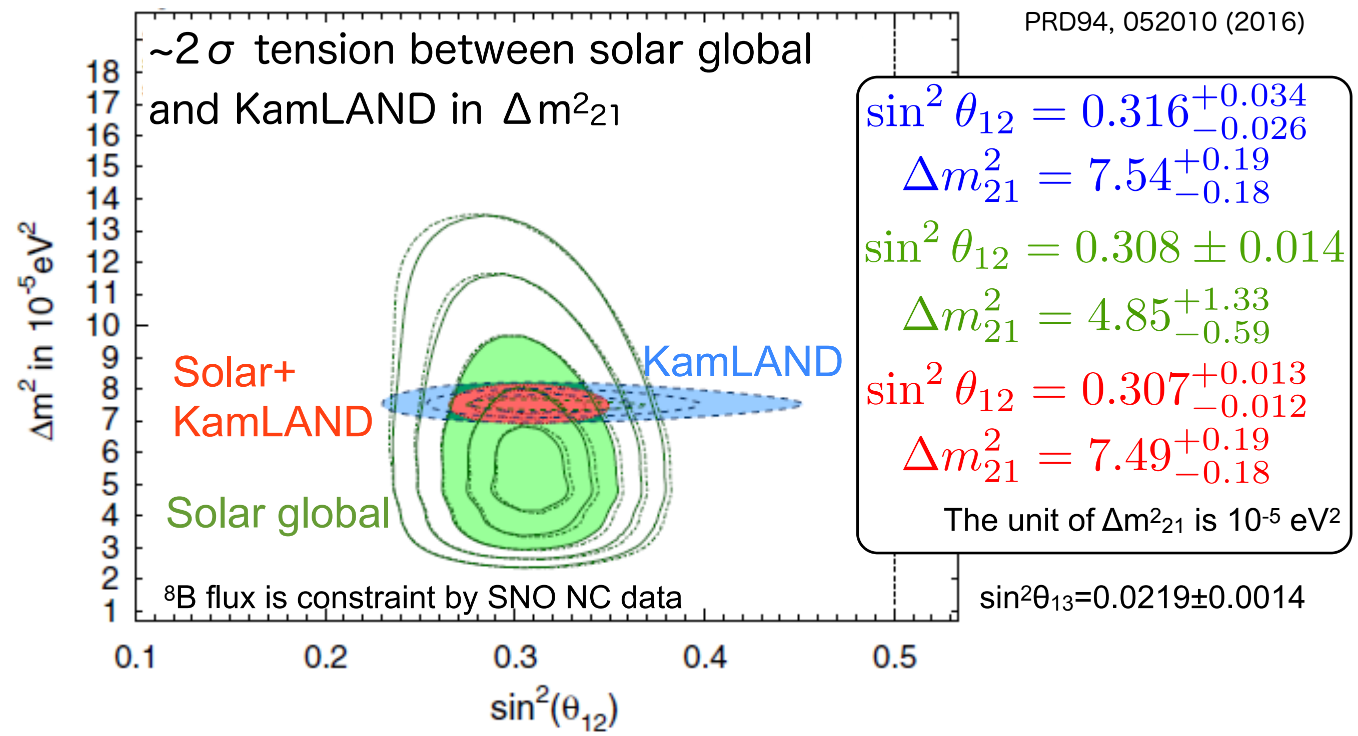
Fraction of δ_{CP} phase space for 3σ observation of CPV

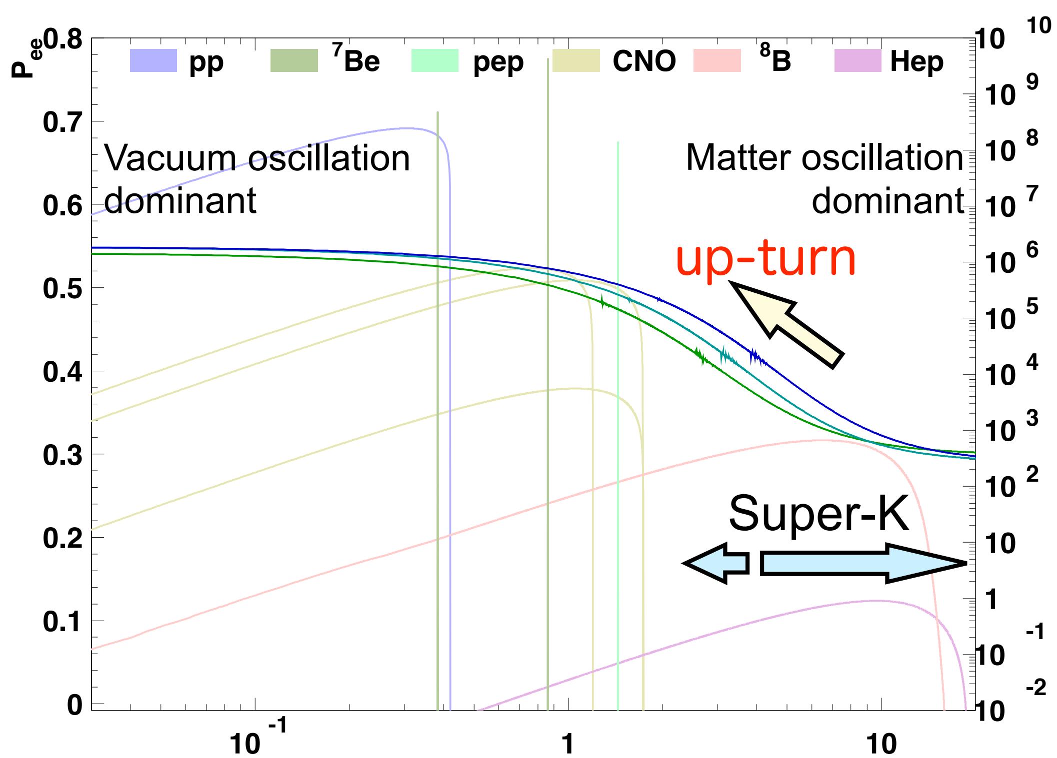


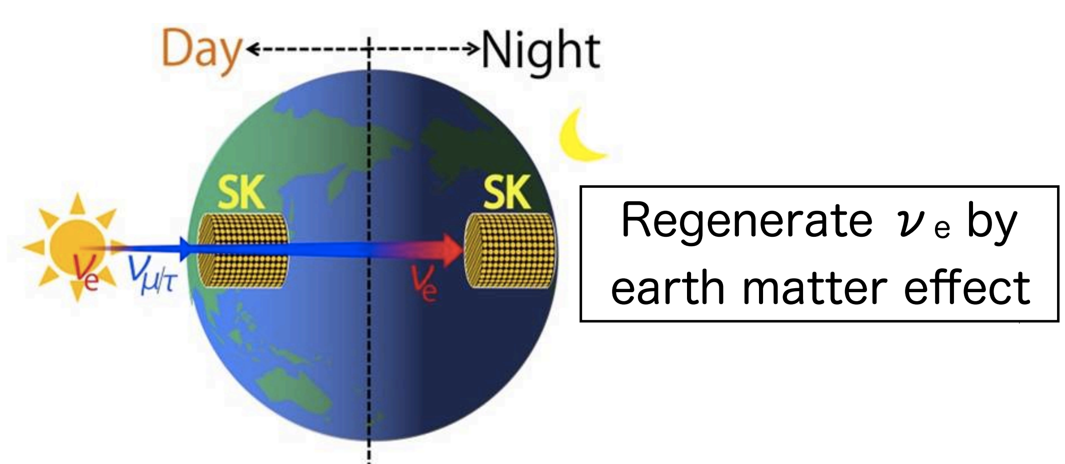
Solar neutrinos

- Unresolved tension between solar and reactor (KamLAND) Δm^2_{21} values
- Super-K's sensitivity to Δm^2_{21} come from spectrum distortion around a few MeV and day-night flux asymmetry
- Hyper-K can independently test this tension with much higher statistics

PRD94, 052010 (2016)



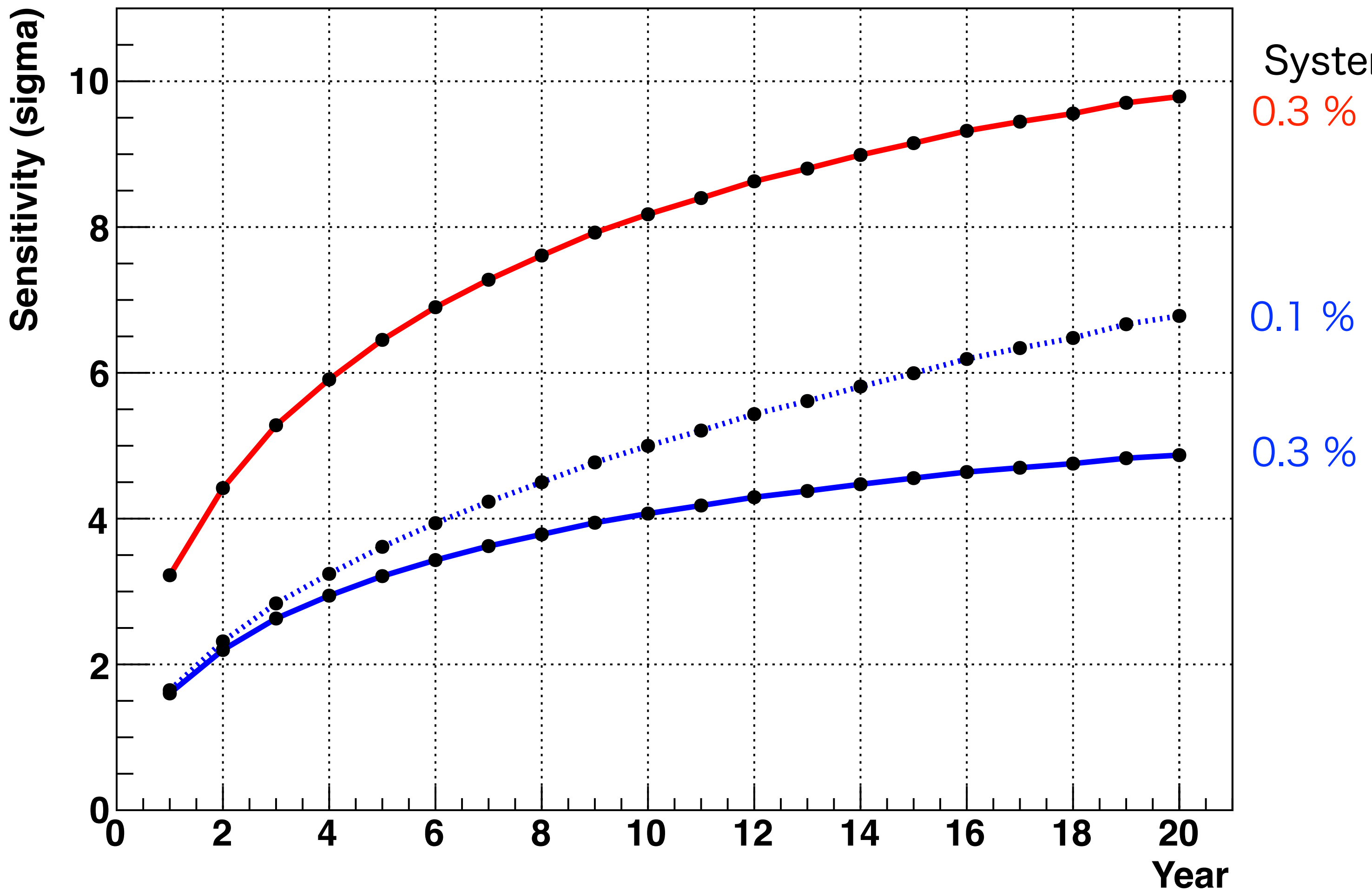


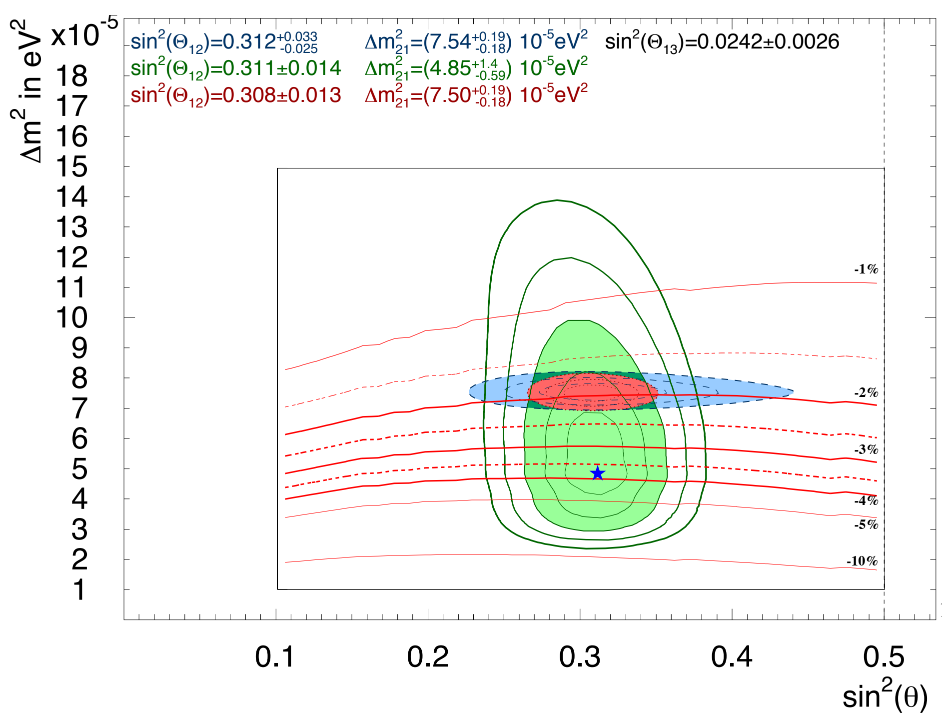


Solar neutrino day/night sensitivity

— Significance for non-zero day/night asymmetry with current solar Δm^2_{21}

— Significance to distinguish current solar and KamLAND Δm^2_{21}

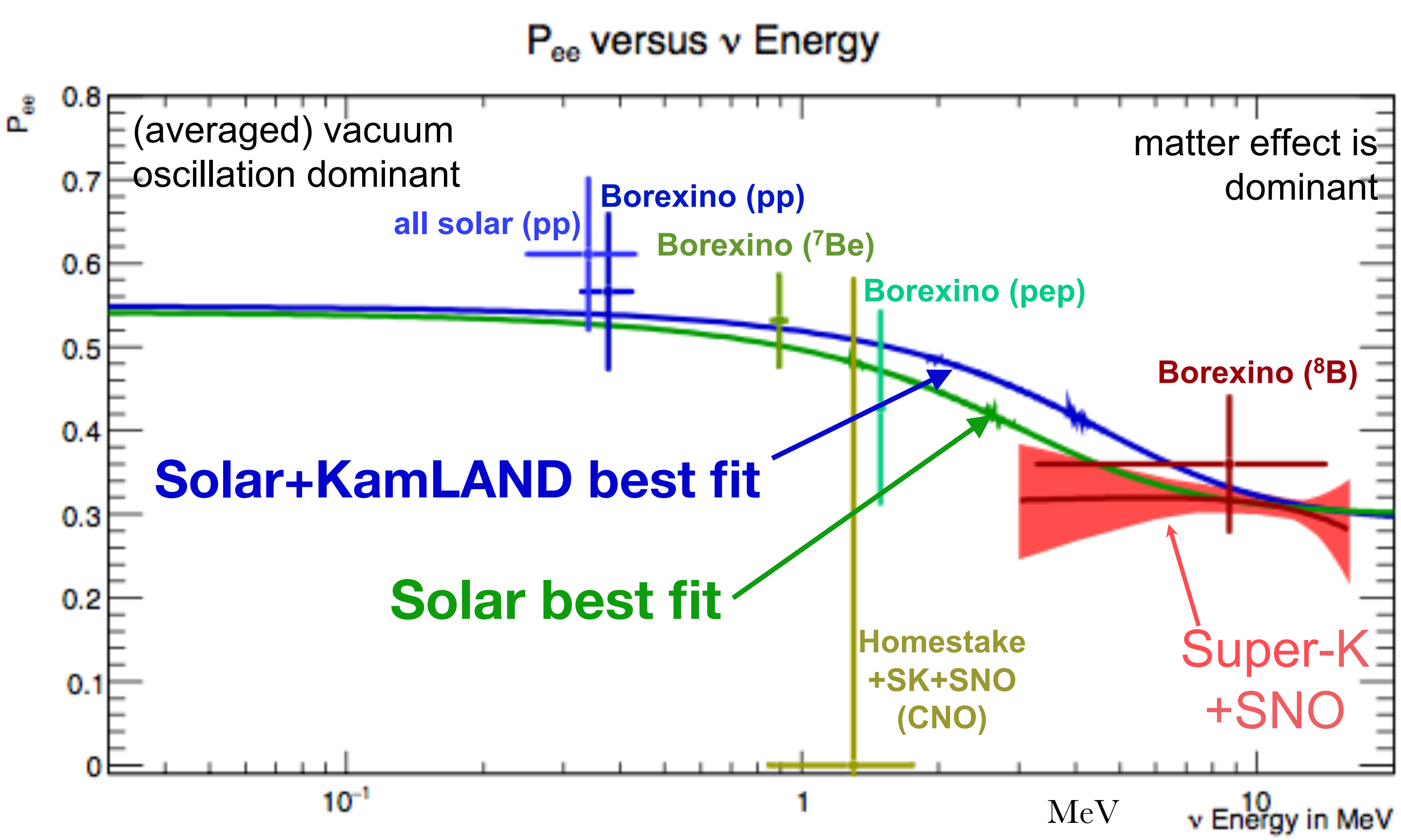




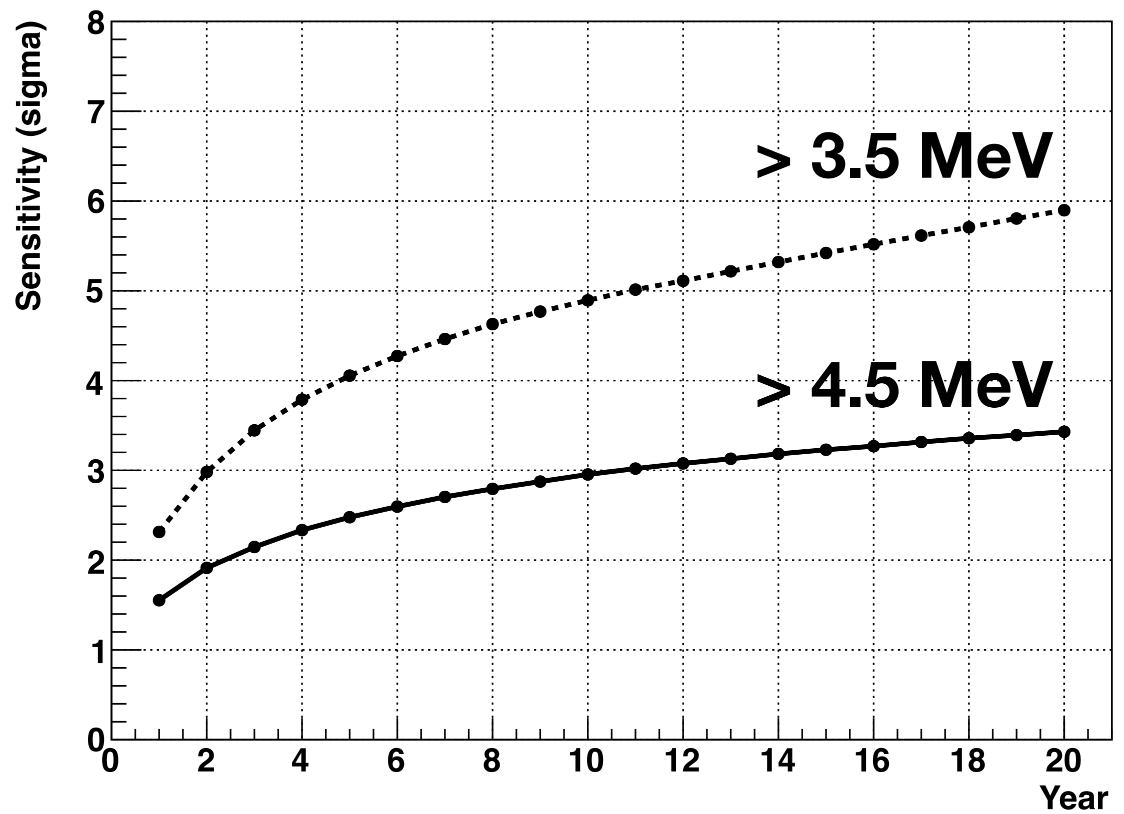
Capable to distinguish the current solar and KamLAND best fit Δm^2_{21} values with 4-5σ significance with ~10 years of data

Solar spectrum upturn measurement

- 3σ (5σ) detection of spectrum upturn possible with 4.5 MeV (3.5 MeV) threshold.
- Achievable energy threshold depends on many factors:
  - Radioactive backgrounds (especially Rn in water)
  - PMT dark rate
  - Energy resolution
  - Spallation backgrounds

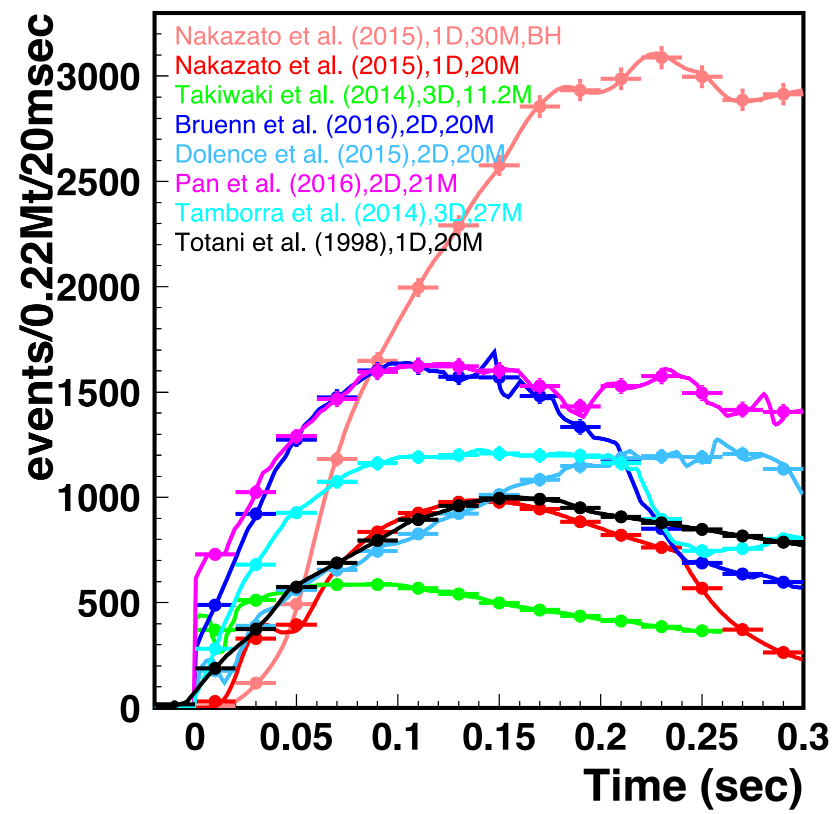


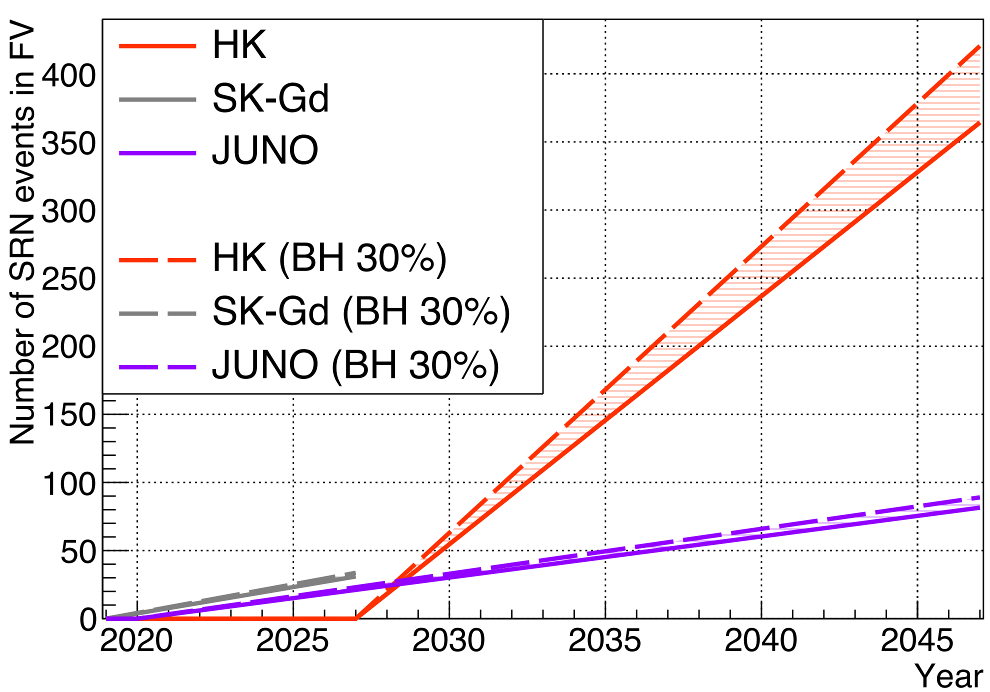
Significance of upturn detection at HK



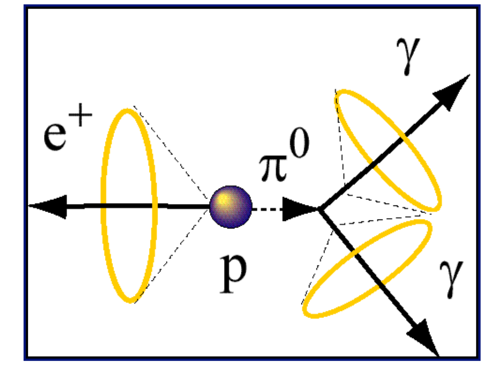
Supernova neutrinos

- Supernova Burst Neutrinos
  - 50k-70k events (mostly inverse beta decay) expected from bursts at 10 kpc (galactic center)
  - Unprecedented statistics to study supernova burst models
- Supernova Relic Neutrinos
  - Diffused neutrinos from the past supernova explosions
  - Retain history of supernova bust in the history of universe from its rate and energy spectrum.
  - Aiming for first detection in SK-Gd
  - HK can make precise study of its energy spectrum with >100 observed events

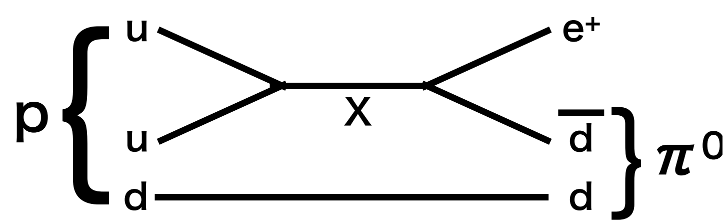




Proton decay

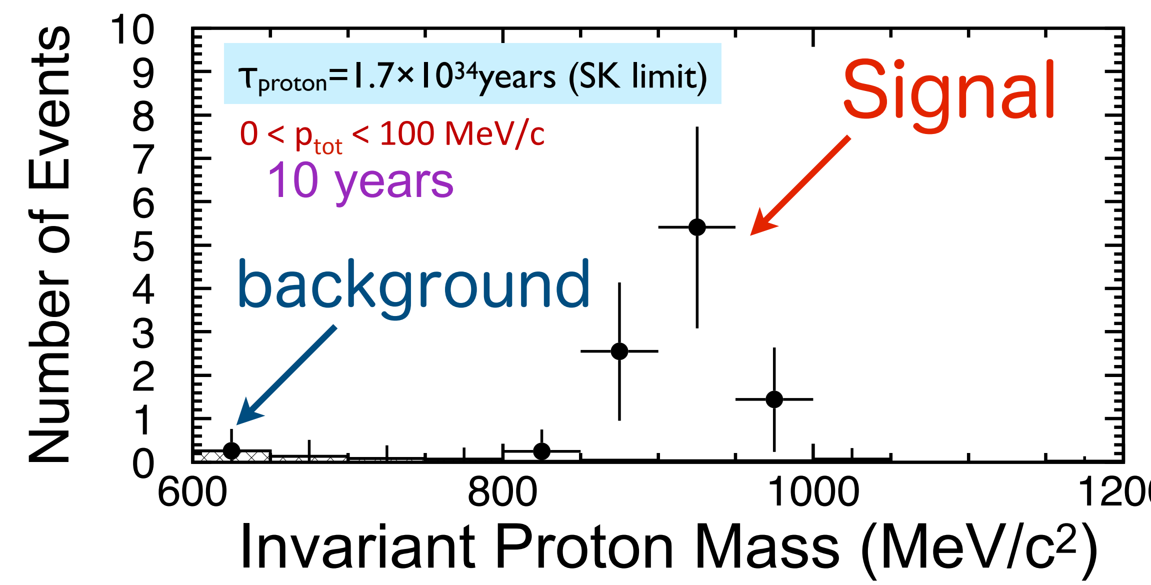


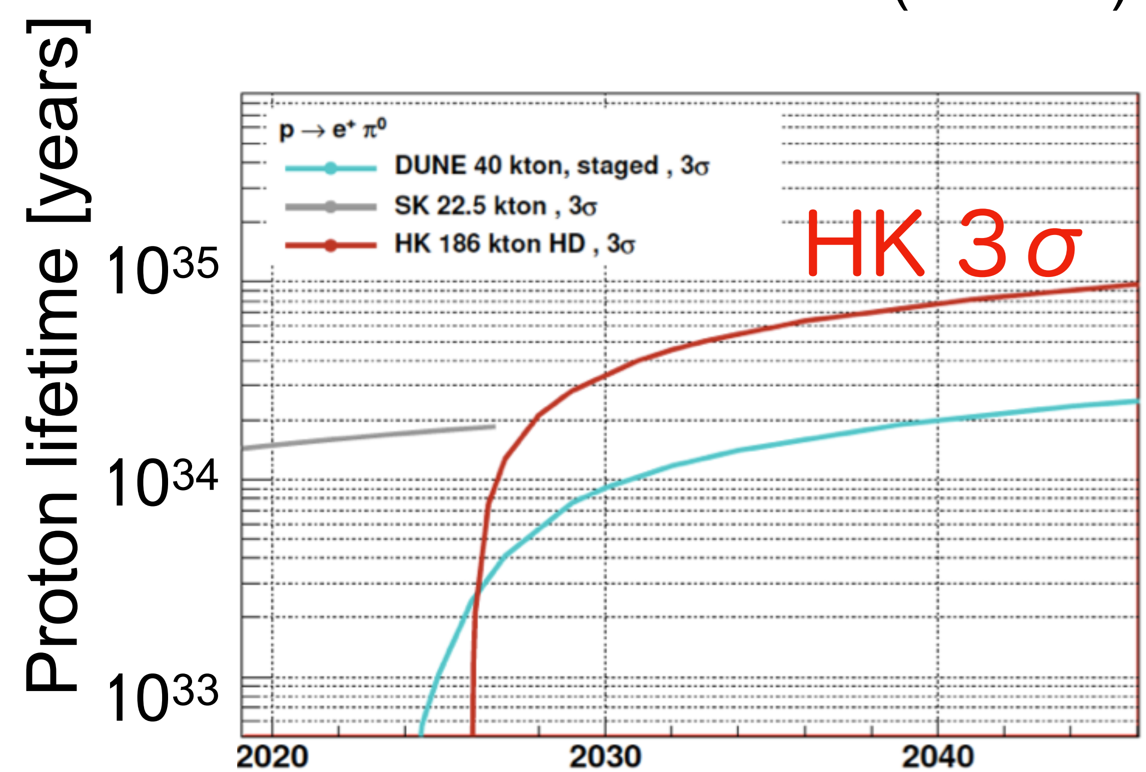
- Direct probe for the Grand Unified Theory



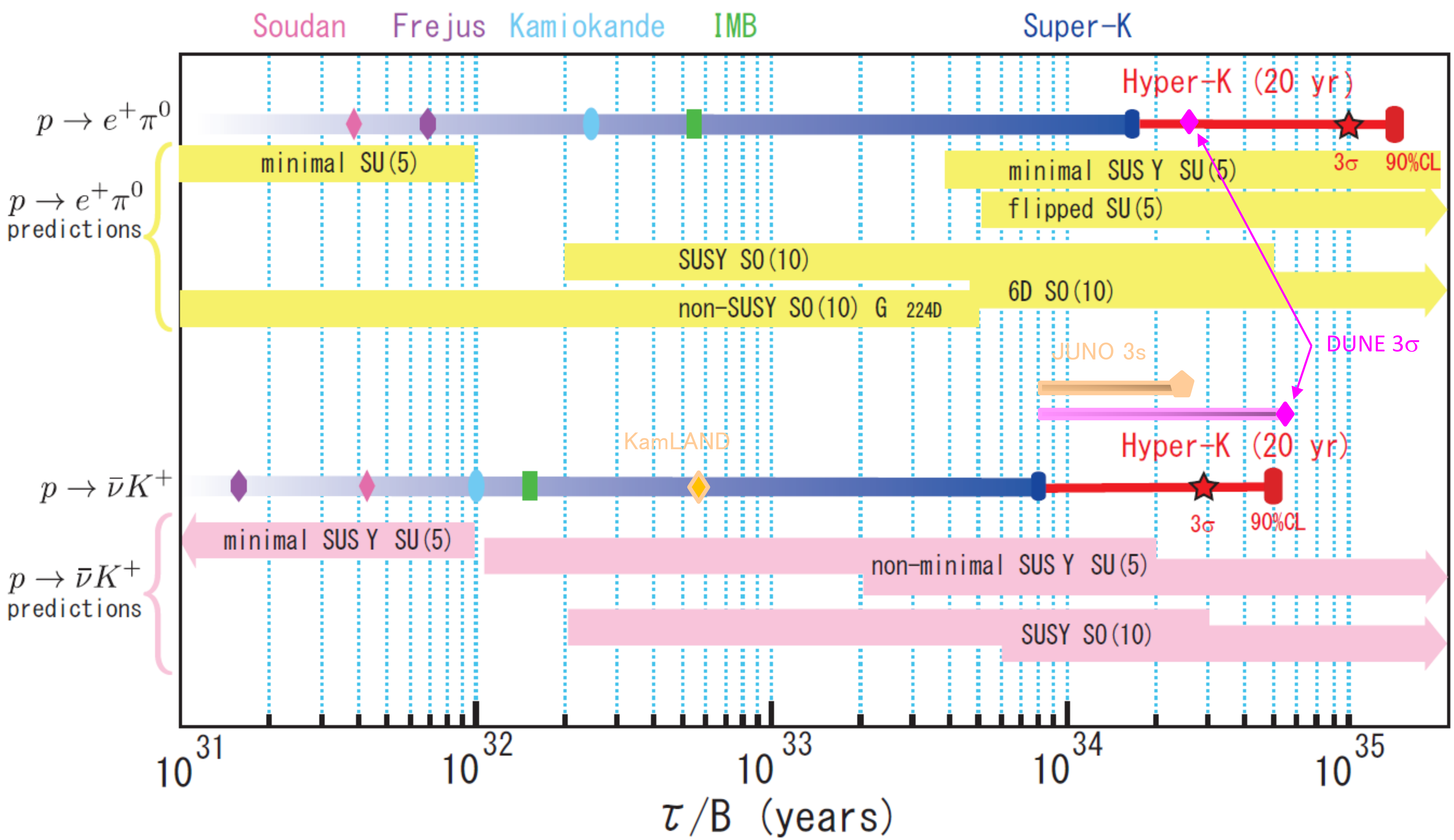
- Previous searches at Super-K found no significant signal
  - ~background free measurement
  - Sensitivity proportional to (# of protons) x (exposure)
- Aiming for an order of magnitude improved search at HK

Expected signal and sensitivity for $p \to e\pi^0$ channel





Proton decay sensitivities



Project status (situation in Japan)

- In the end of Aug. 2018, MEXT has decided to request the budget to Ministry of Finance for ***"funding for feasibility study"***
    - Super-Kamiokande also received the "funding for feasibility study" in 1990, and the construction budget was approved in 1991
- Then, the President of the Univ. of Tokyo, in recognition of both the project's importance and value both nationally and internationally, ***pledged to ensure construction of the Hyper-Kamiokande detector commences as scheduled in April 2020.***

Hyper-K construction shall start in 2020
(aim to start operation in ~2027)

Summary

- The Hyper-Kamiokande project: Next generation neutrino and nucleon decay experiment with
  - Huge water Cherenkov Detector with ~190 kton FV
  - High-intensity neutrino beam from 1.3 MW proton beam at J-PARC
  - Upgraded near detector system
- Unique capability of studying wide variety of physics
  - Precision study of neutrino oscillation and CP violation in the lepton sector
  - Neutrino astrophysics
  - Search for nucleon decays
- Construction to start in 2020, aiming to start observation in 2027