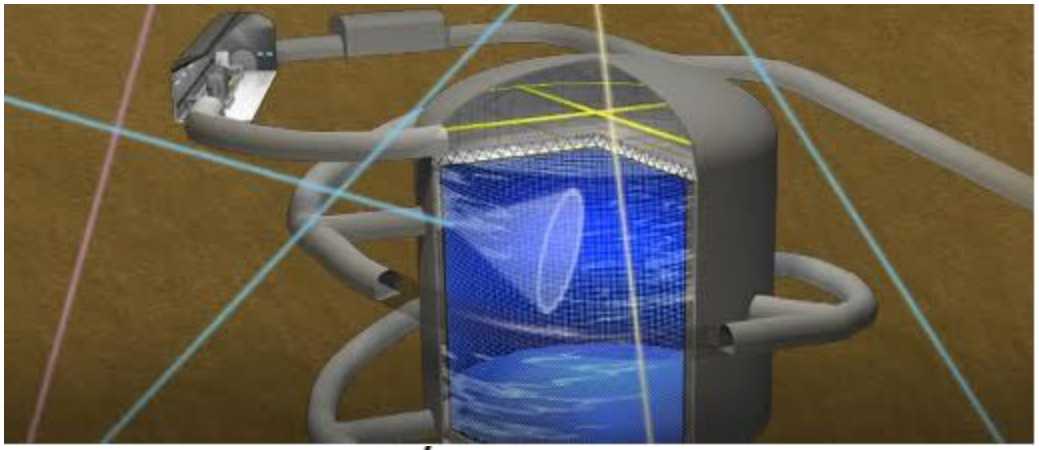
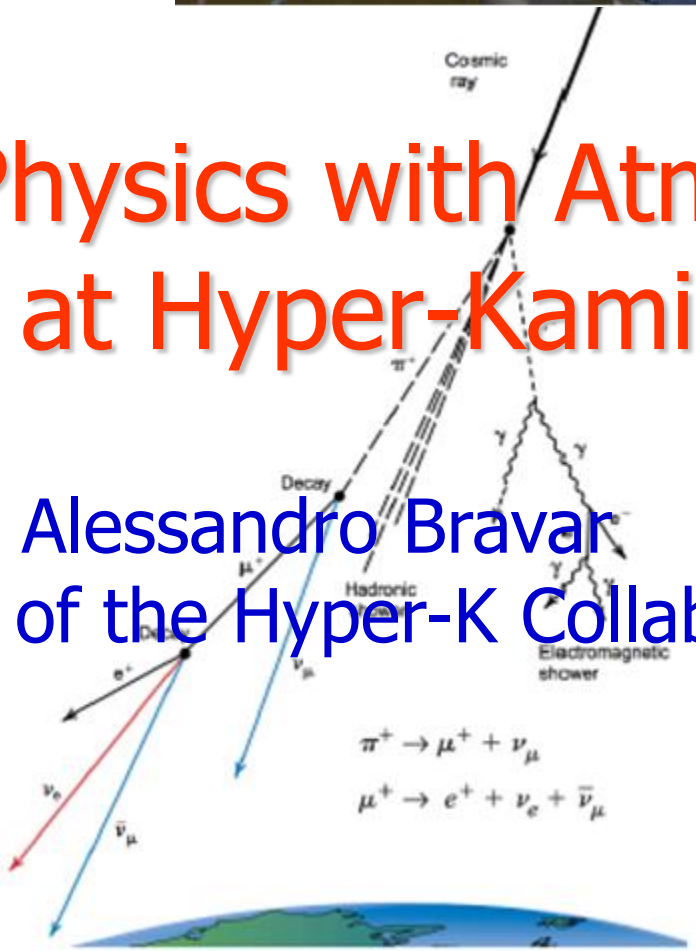
Hyper-Kamiokande

http://hyperk.org



Oscillation Physics with Atmospheric Neutrinos at Hyper-Kamiokande

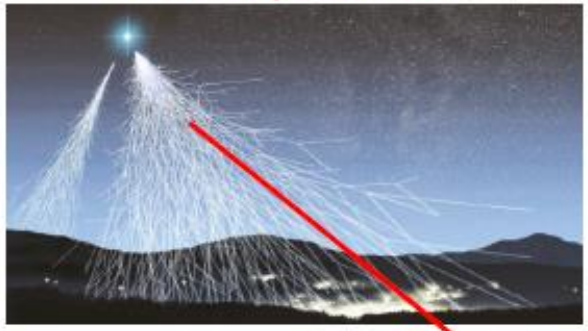
Alessandro Bravar
on behalf of the Hyper-K Collaboration



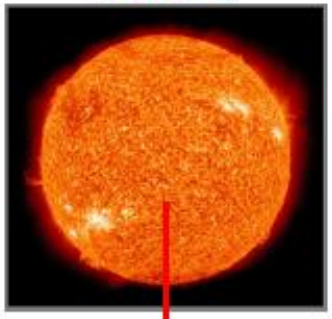
ICHEP2017
Seoul, July 05, 2018

Hyper-K Physics Overview

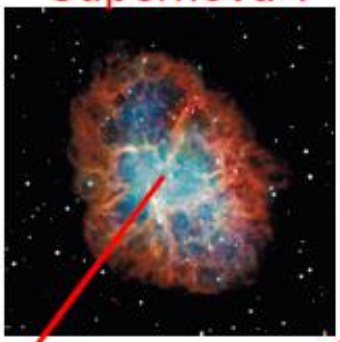
Atmospheric ν



Solar ν

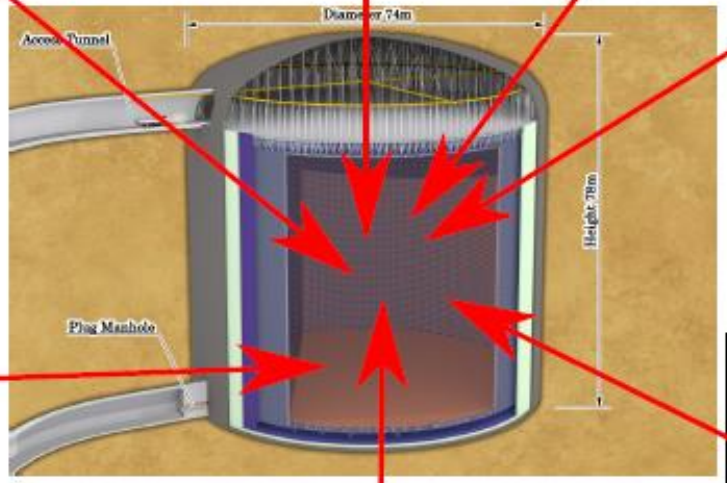


Supernova ν



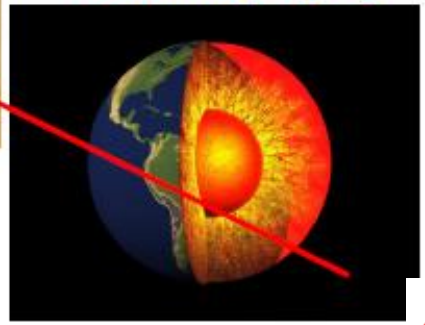
WIMP χχ -> νν

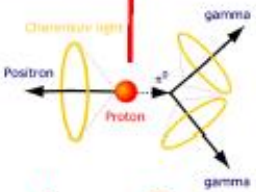
Beam ν



+ unexpected (unknown)

ν Tomography





Nucleon Decay

Atmospheric Neutrinos

Isotropic flux of cosmic rays

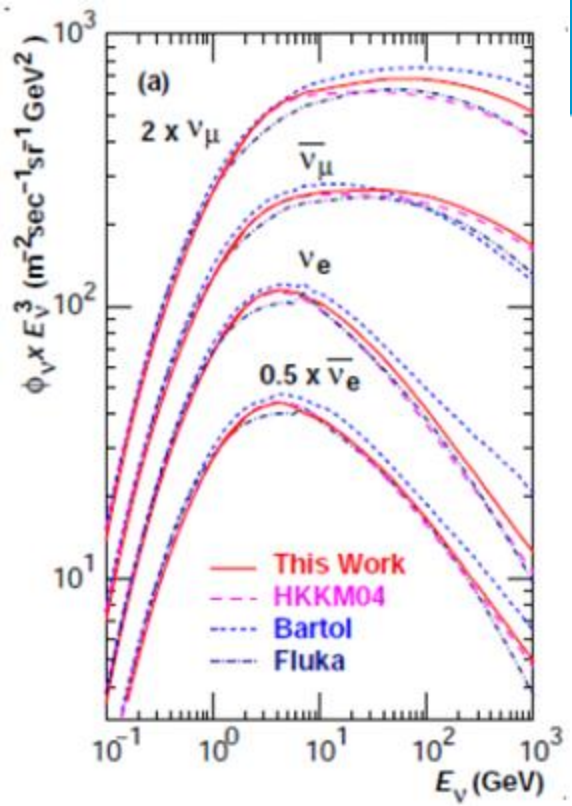
Large range of neutrino energies
ν_μ , $\overline{\nu}_\mu$, ν_e , $\overline{\nu}_e$ over several decades in energy

Baseline from 10 km to 13,000 km

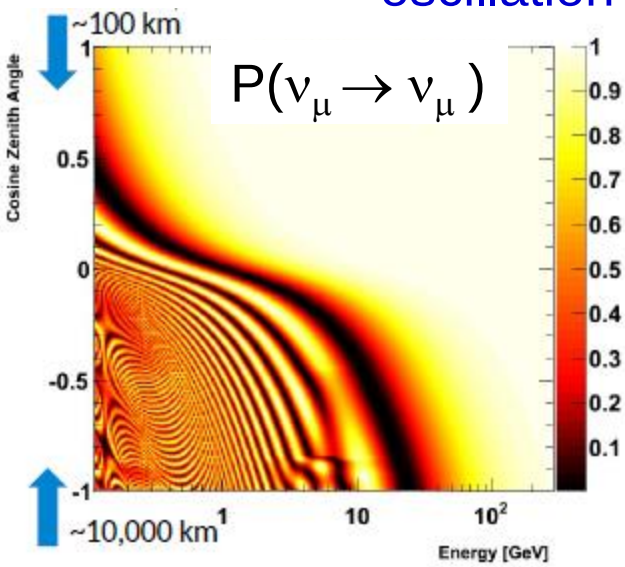
Oscillation dominated by $\nu_\mu \rightarrow \nu_\tau$

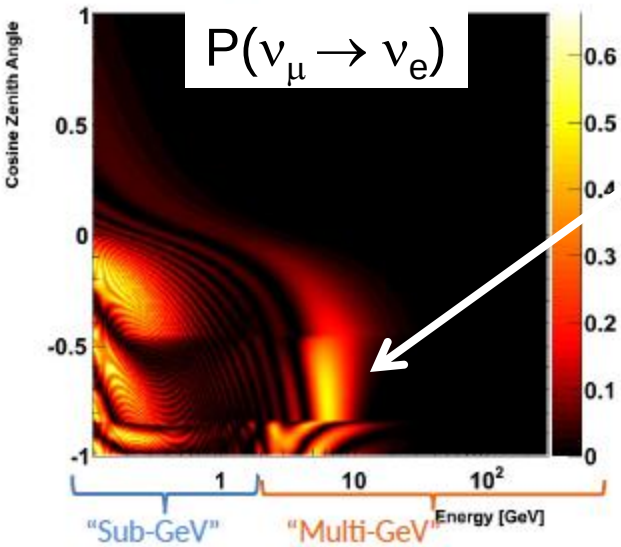
In principle, sensitive to all PMNS parameters

With larger statistics, they can also provide information on sub-leading effects



oscillation probabilities





resonant oscillations between 2 - 10 GeV lead to enhancement of $\nu_\mu \rightarrow \nu_e$ (NH) or $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ (IH) appearance probability for upward-going neutrinos

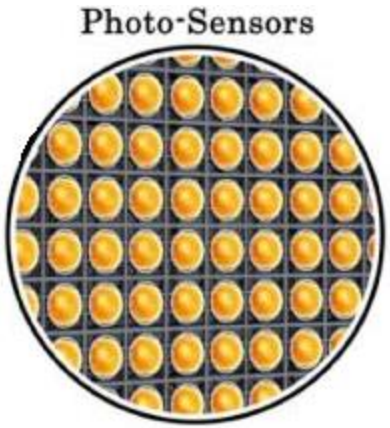
The Hyper-Kamiokande Detector

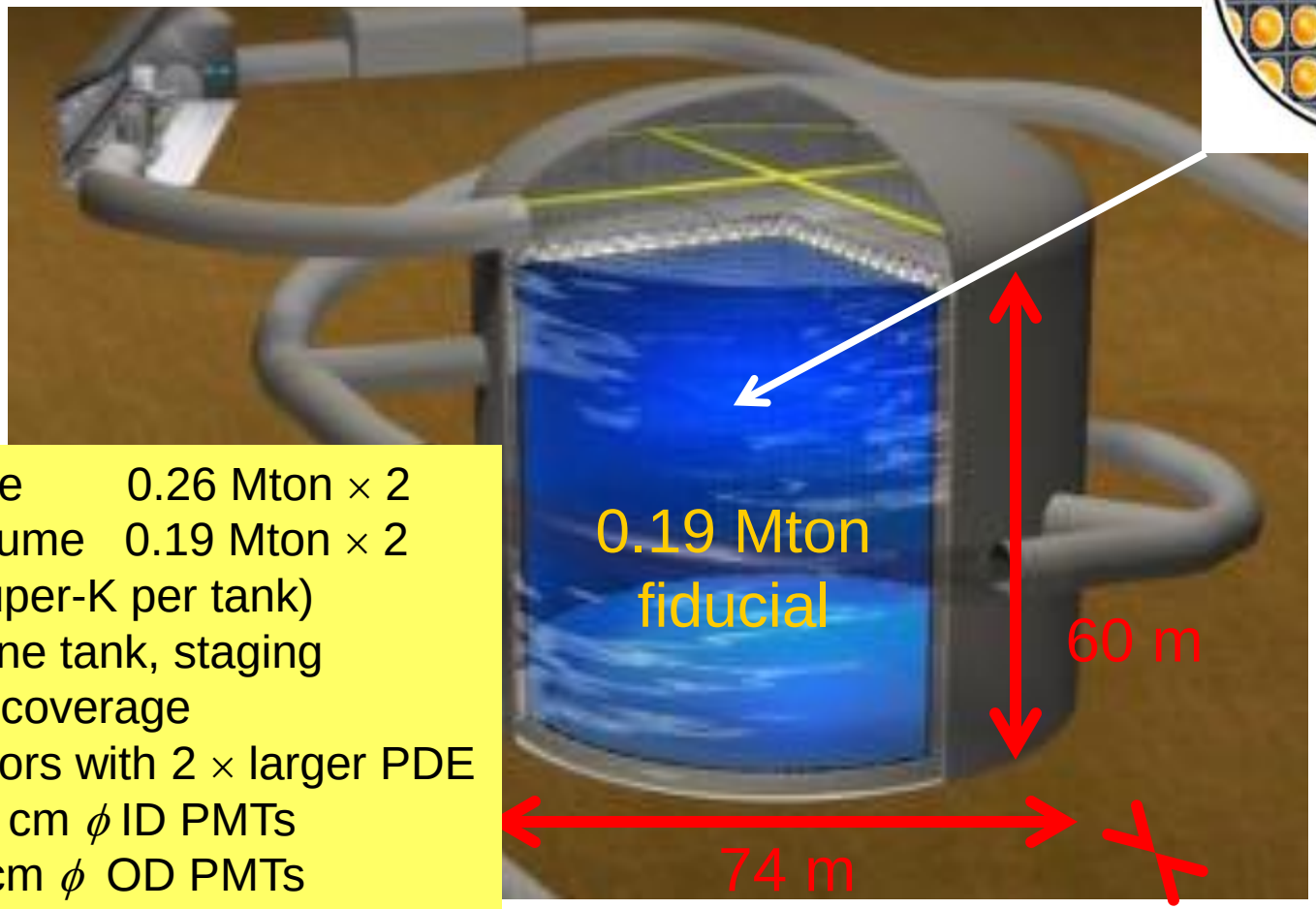
Large Water Cherenkov Detector

Larger mass for more statistics

Better sensitivity by more photons with improved sensors

Overburden ~650 m (~1755 m w.e.)

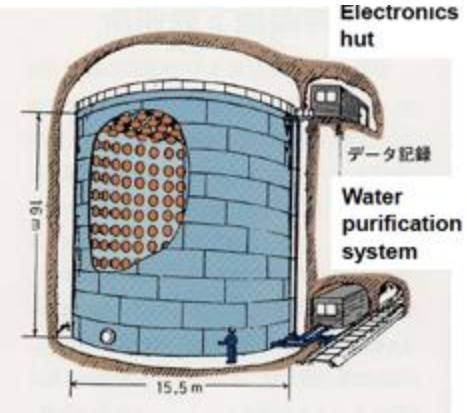




Total volume 0.26 Mton × 2
Fiducial volume 0.19 Mton × 2
(~10 × Super-K per tank)
Start with one tank, staging
40% photo-coverage
new sensors with 2 × larger PDE
40,000 50 cm ϕ ID PMTs
6,700 20 cm ϕ OD PMTs

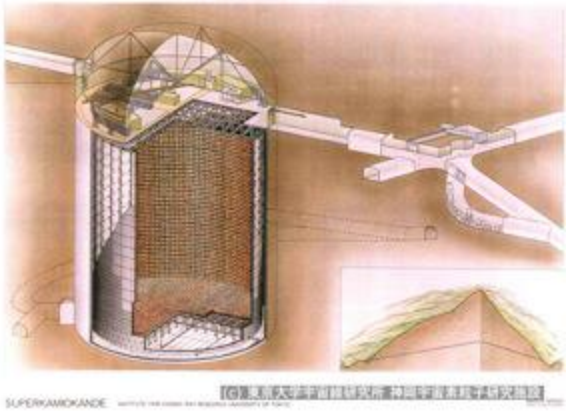
3 Generations of Kamioka Detectors

Kamiokande
(1983-1996)



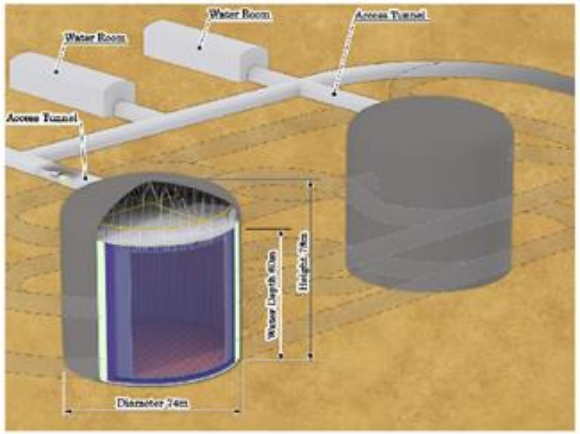
3 kton
20% coverage
with 50 cm PMT

Super-Kamiokande
(1996-)



50 kton
40% coverage
with 50 cm PMT

Hyper-Kamiokande
(~2026-)



260 kton × 2
40% coverage with
high-QE 50 cm PMT

Observation of SN1987A

Discovery of
ν oscillations

?

Prepare for the unknown

Zenith Angle Distributions

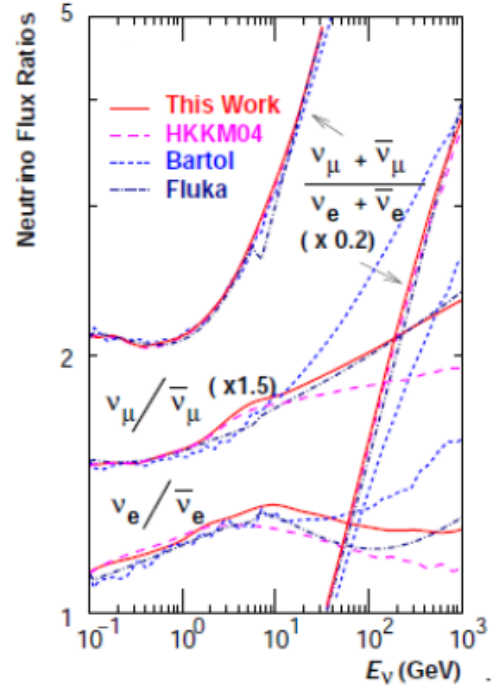
Isotropic flux of cosmic rays

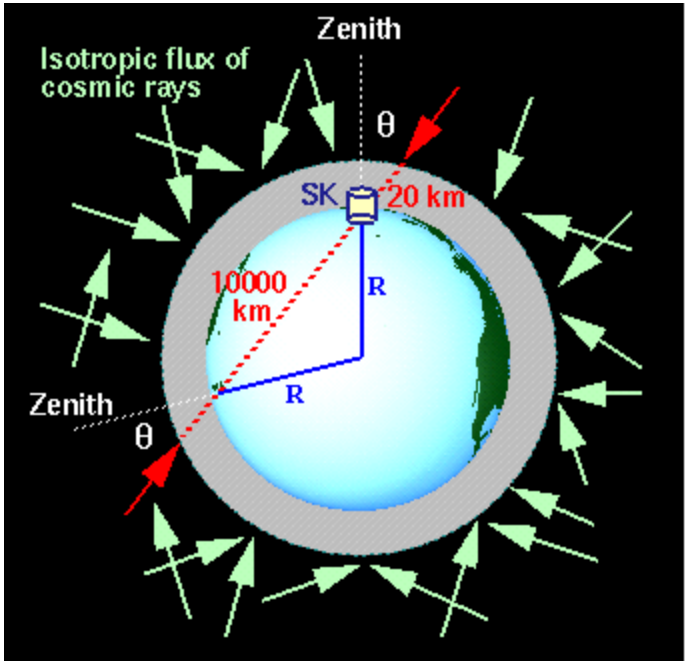
Large range of neutrino energies
ν_μ , $\overline{\nu}_\mu$, ν_e , $\overline{\nu}_e$ over several decades in energy

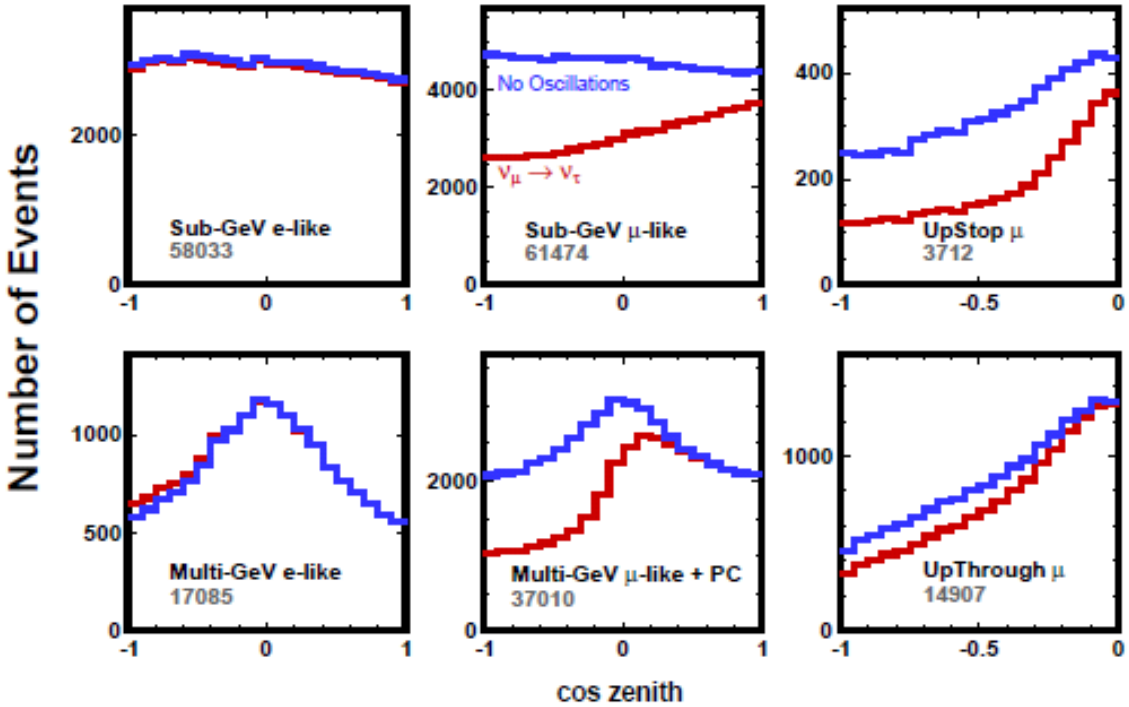
Baseline from 10 km to 13,000 km

Oscillation dominated by $\nu_\mu \rightarrow \nu_\tau$

In principle, sensitive to all PMNS parameters







Mass Hierarchy and Octant Sensitivities

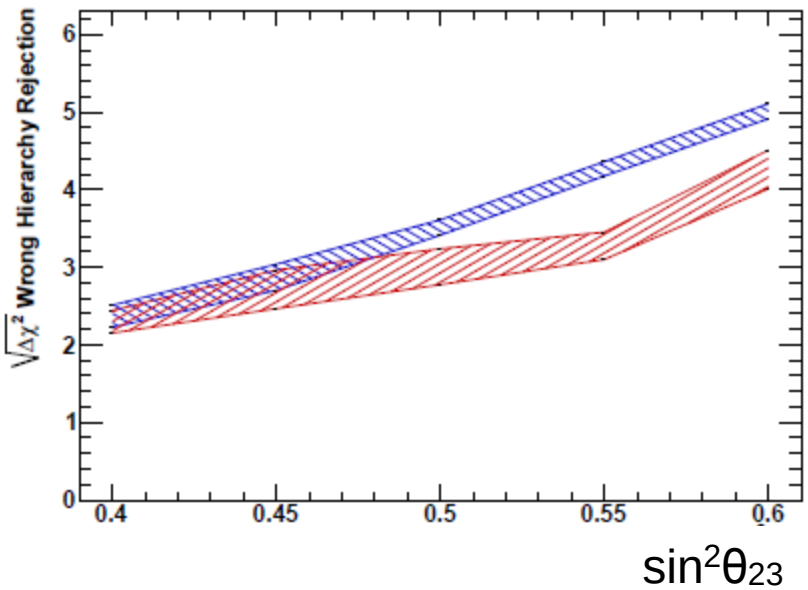
atmospheric ν only (1.9 Mton year exposure)

Determine mass hierarchy at 3σ when $\sin^2\theta_{23} > 0.53$ through matter induced resonances

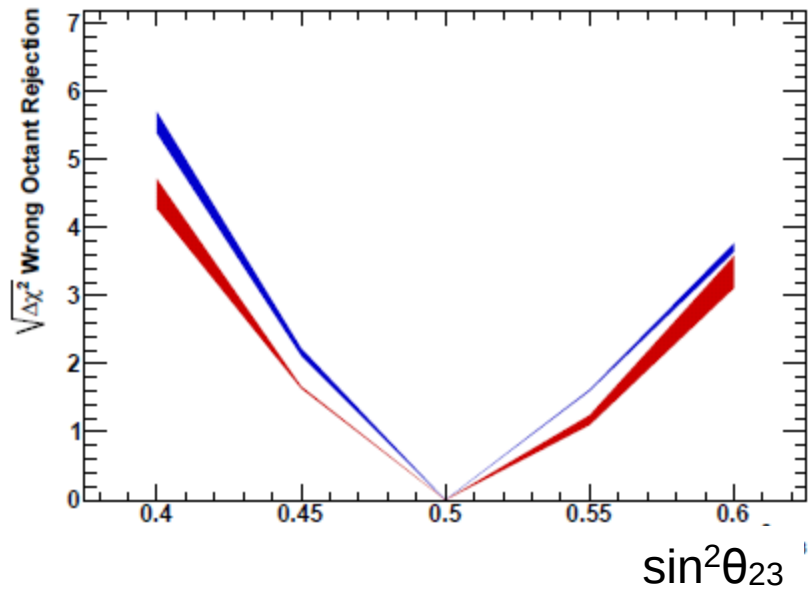
Some sensitivity to θ_{23} octant, can resolve the octant at 3σ if $|\theta_{23}-45^o|>4^o$

Sensitivities depend on true θ_{23} value

mass hierarchy determination



octant determination

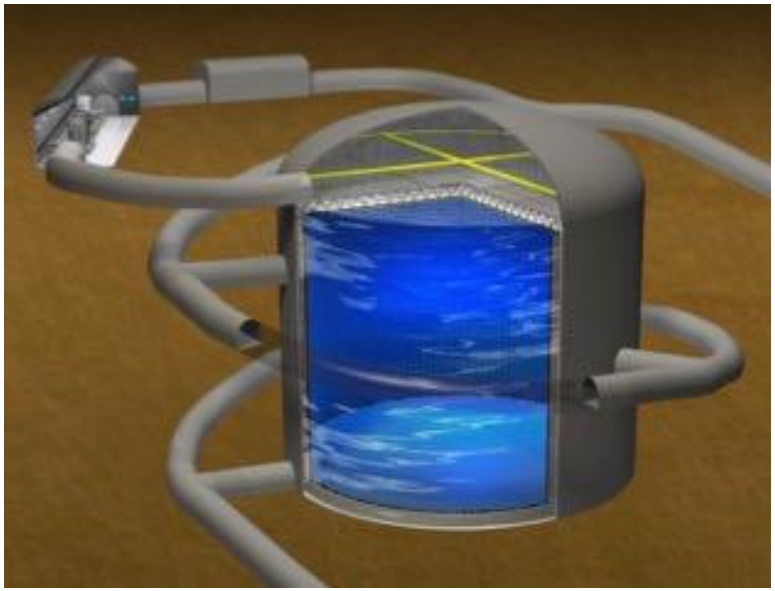


uncertainty from δ_{CP} is shown by the width of the bands

From J-PARC to Kamioka (T2HK)

Atmospheric + beam neutrinos → precision oscillation parameter measurements

260 kton Water Cherenkov Detector



+

Upgraded J-PARC neutrino beam
New / upgraded near detectors

T2HK: Sensitivity to Atmospheric param.

beam + atmospheric (1.9 Mton year exposure)

$\delta(\Delta m^2_{32}) \sim 1.4 \times 10^{-5}\ eV^2$ (i.e. 0.6% precision)

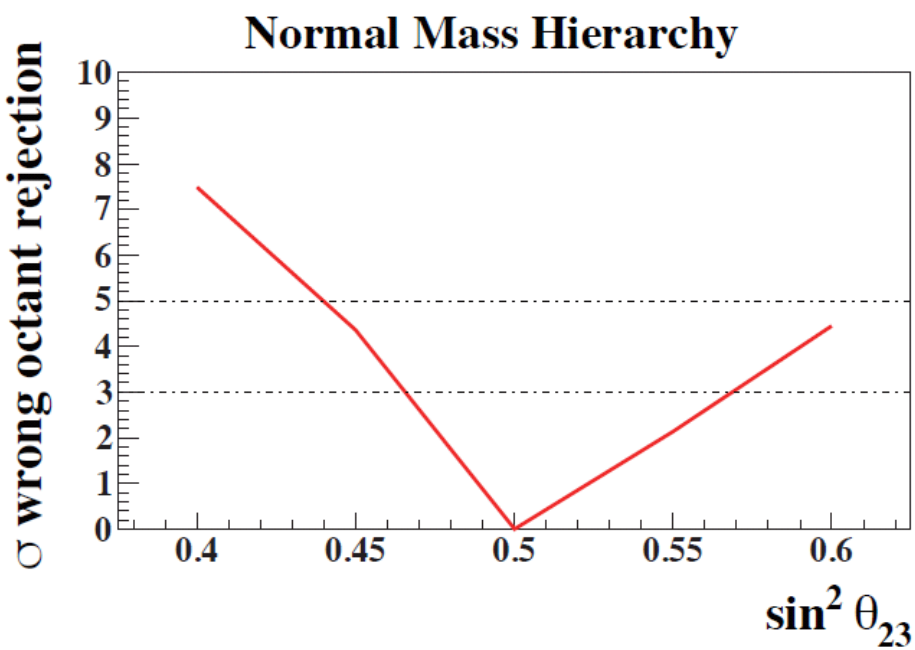
→ mass hierarchy sensitivity (with reactor constraint)

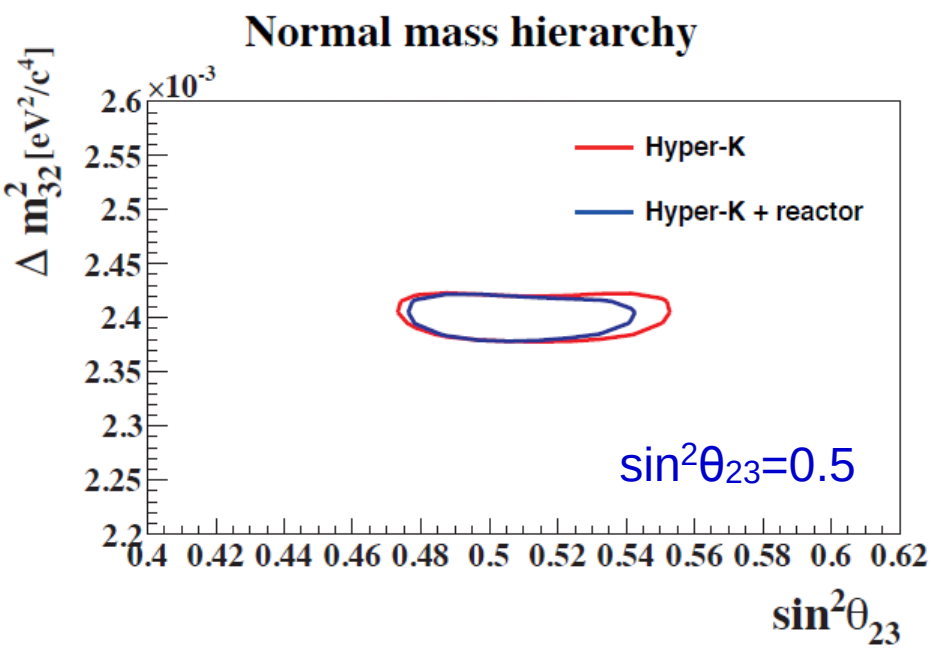
$\delta(\sin^2\theta_{23}) \sim 0.015$ (for $\sin^2\theta_{23} = 0.5$)

~ 0.006 (for $\sin^2\theta_{23} = 0.45$)

→ some ability to determine octant of θ_{23}

joint fit of ν_μ and ν_e samples to precisely measure $\sin^2\theta_{23}$ and Δm^2_{32}





T2HK: Sensitivity to Mass Hierarchy

beam + atmospheric (1.9 Mton year exposure)

Atmospheric neutrinos

Sensitive to mass hierarchy through matter induced resonance

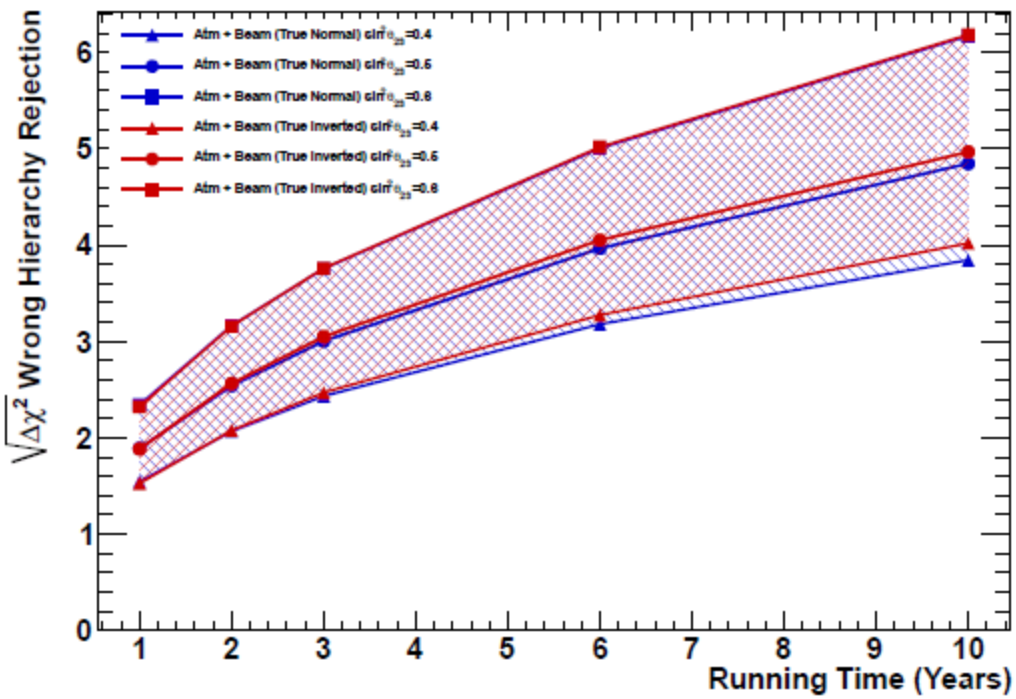
Size of the effect depends of θ_{23}

Limited precision for θ_{23} and $|\Delta m^2_{32}|$

Beam neutrinos

Good precision for θ_{23} and $|\Delta m^2_{32}|$ measurements

Very limited sensitivity to MH



Combining the two

>3σ ability to reject wrong MH

5σ for larger values of $\sin^2\theta_{23}$

True $\sin^2\theta_{23}$	Atmospheric only	Atmospheric +beam
0.4	2.2 σ	3.8 σ
0.6	4.9 σ	6.2 σ

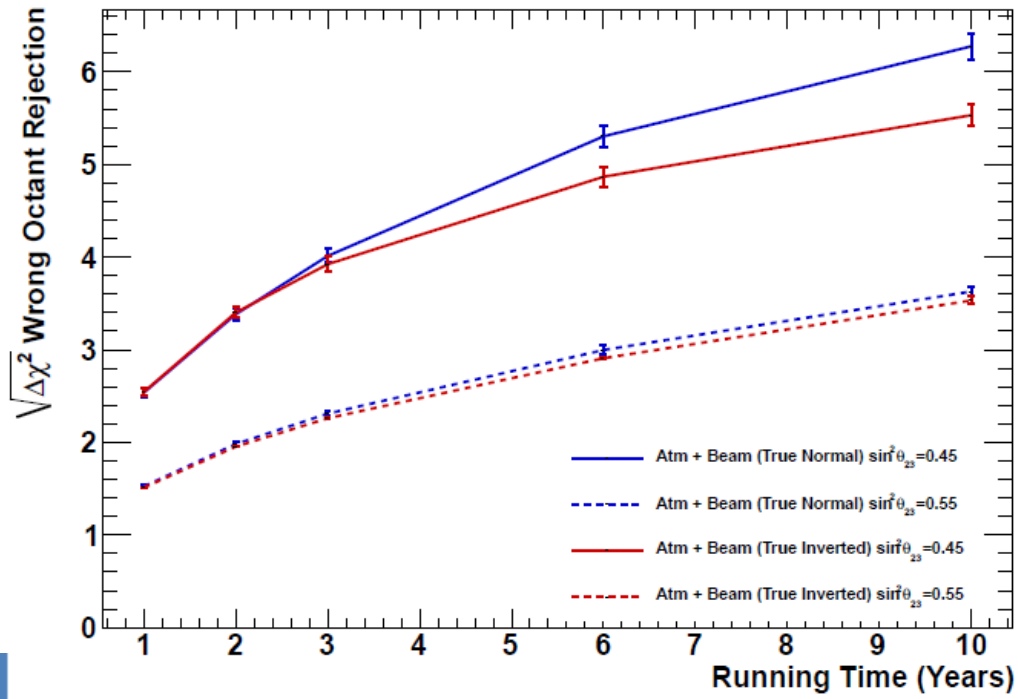
T2HK: Octant Resolution Sensitivity

beam + atmospheric (1.9 Mton year exposure)

The ability to resolve the θ_{23} octant improves with the combination of atmospheric and beam neutrinos

Atmospheric neutrinos alone can resolve the octant at 3σ if $|\theta_{23}-45^o|>4^o$

In a combined analysis it can be resolved when this difference is only 2.3°



True $\sin^2\theta_{23}$	Atmospheric only	Atmospheric +beam
0.45	2.2 σ	6.2 σ
0.55	1.6 σ	3.6 σ

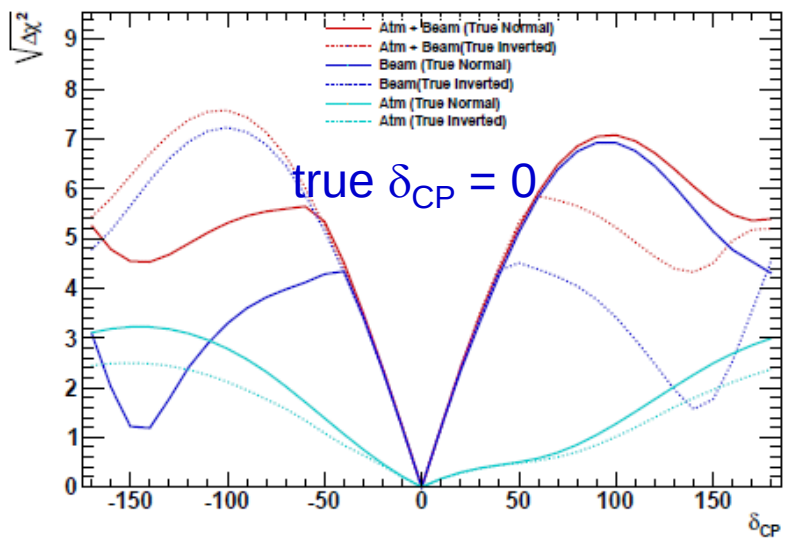
T2HK: Sensitivity to CP Violation

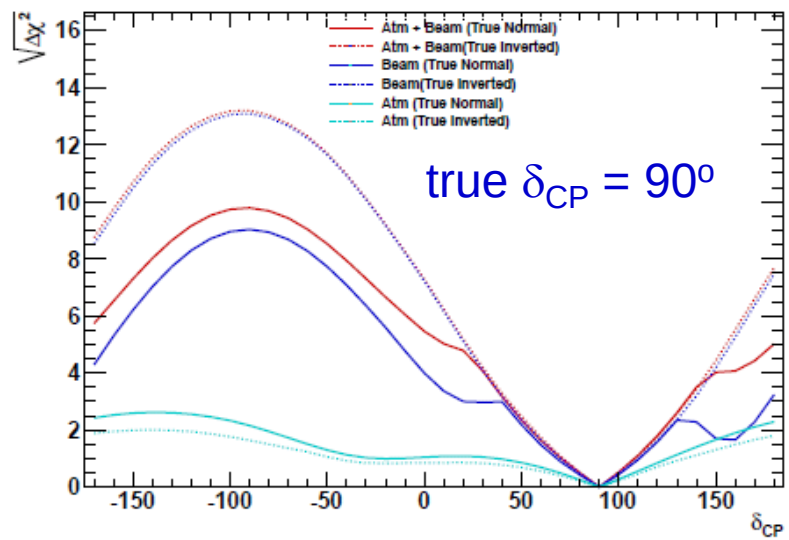
beam + atmospheric (1.9 Mton year exposure)

Sensitivity to CP violation mainly dominated by beam neutrinos
Atmospheric neutrino sensitivity limited by flux/cross section uncertainties

Sensitive to cos δ_{CP}

Atmospheric neutrinos allow to break possible degeneracies between MH and δ_{CP} when MH is unknown





Hierarchy is assumed to be unknown in these plots

More Physics with Atmospheric ν

Atmospheric ν:
neutrinos with various energy, flight length, and flavor

ν_τ cross section measurement

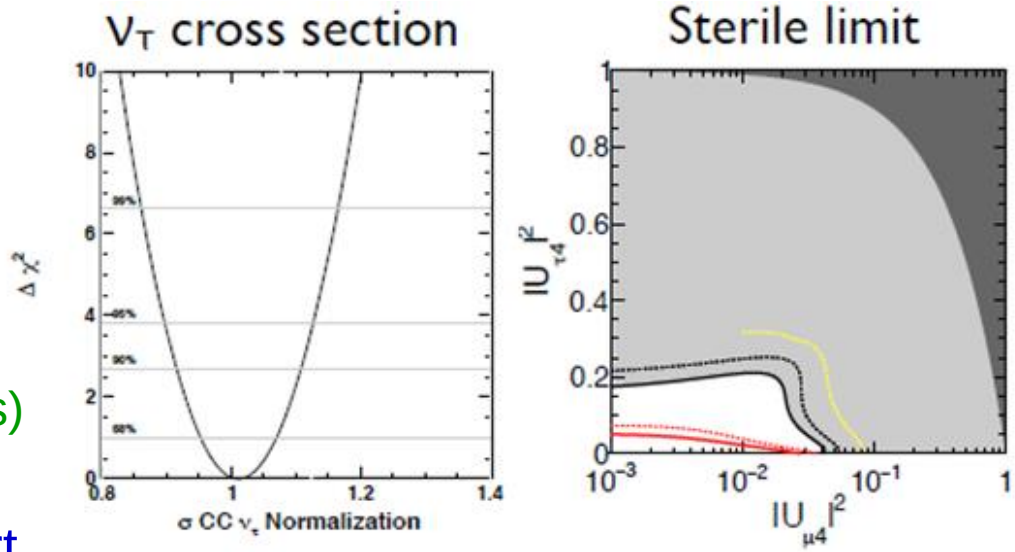
Sterile neutrinos

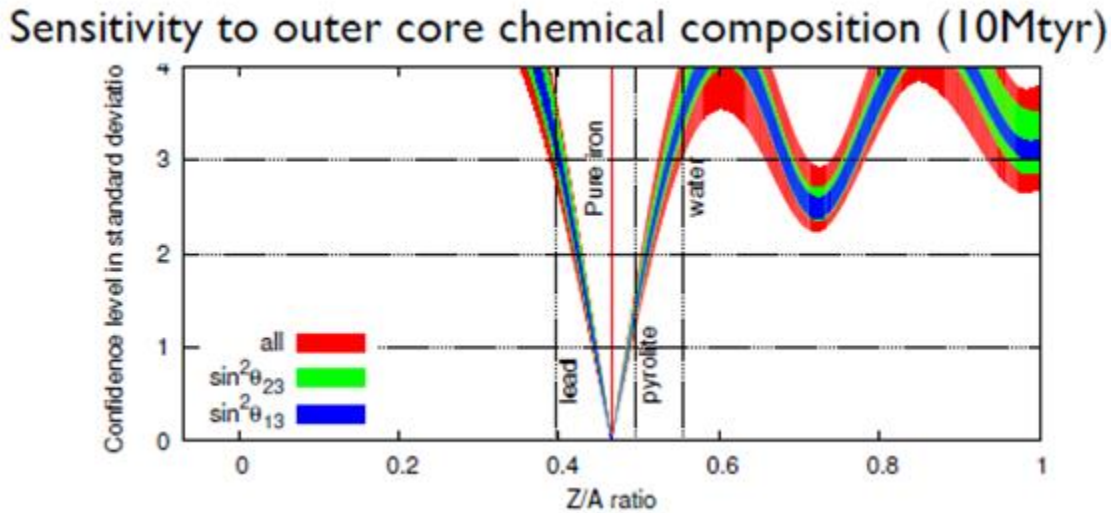
Lorentz violation studies
(3 – 4 × stronger than current SK limits)

dark matter annihilation into SM part.
(3 – 5 × stronger than current SK limits)

Geophysics
chemical composition of Earth's outer core using matter effect

(5.6 Mton year exposure)





Conclusions

A new adventure in ν Physics to start

Proto-Collaboration established on January 15th 2015
Collaboration growing ~300 members from 15 countries

A rich physics program:

- atmospheric, SN, solar, accelerator neutrinos
- proton decay

Optimized detector configuration:

- built on successful technology established with past/ongoing experiments
- larger detector
- improved PMTs (2 x higher QE)

Atmospheric neutrino analyses benefit the most from increased statistics

- expect better than ~3σ sensitivity to the mass hierarchy using atmospheric neutrinos alone (~5σ combining atm + beam ν)
- octant resolution at 3σ if $|\theta_{23}-45^o|>4^o$ (2.3^o combining atm + beam ν)
- neutrino and antineutrino separation with neutron tagging (will benefit mass hierarchy and increase δ_{CP} sensitivity)

The Hyper-K Collaboration

Formed in Jan. 2015

15 countries

~300 members
(and gowing)