Hyper-Kamiokande Project

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for the Hyper Kamiokande working group

Neutrino oscillation and parameters

PMNS Matrix ($U_{\alpha i}$)

Finally, θ_{13} was confirmed to have non-zero value.

$s_{ij}=\sin\theta_{ij}$, $c_{ij}=\cos\theta_{ij}$

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\frac{\alpha_{21}}{2}} & 0 \\ 0 & 0 & e^{i\frac{\alpha_{31}}{2}} \end{pmatrix}$$

(Atm. + Accl.) **(T2K + Reactor)** **(Solar + Reactor)**

$\sin^2 2\theta_{23} \sim 1 (>0.9)$ $\sin^2 2\theta_{13} \sim 0.1$ $\sin^2\theta_{12} \sim 0.3$

(0.099 ± 0.014)

Remaining questions related to neutrino mixing

1) $\theta_{23} = 45^o$ or $< 45^o$ or $>45^o$
2) CP violated or not ($\delta = 0$ or not)
3) Mass hierarchy $\Delta m_{32} > 0$ or < 0

Properties of neutrinos ~ remaining issues

- CP conserved or violated in lepton sector? ($\delta = 0$ or $\neq 0$?)

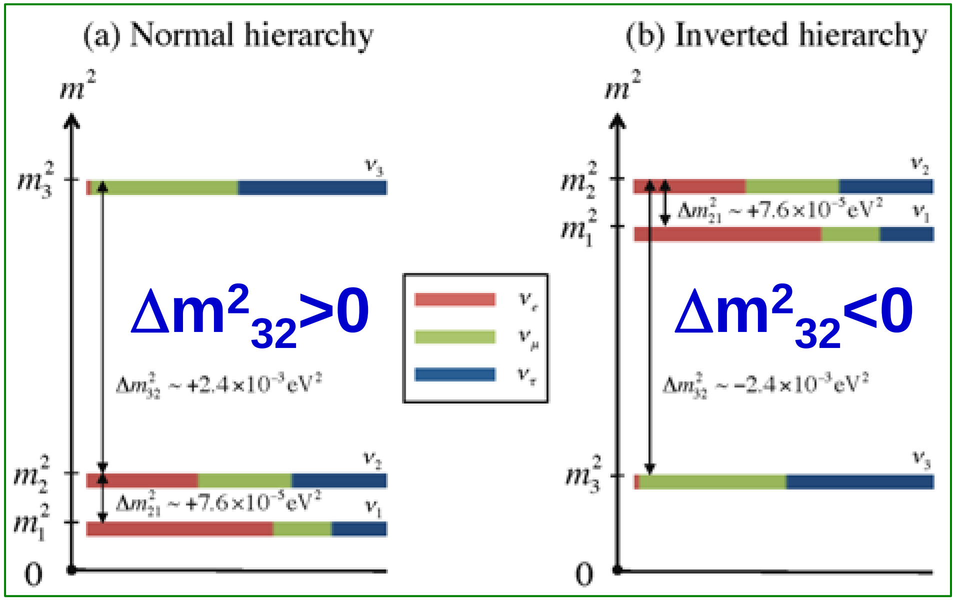
    Related to Matter – Antimatter asymmetry ??

- Mass hierarchy (relation between m_3 and m_2)

    Only ($|\Delta \mathbf{m}^2_{32}|$) is known.

    Related to the decay prob. of 0ν double β decays

    Related to the source of the neutrino mass?



- θ_{23} Full mixing or not?

    If not full mixing, $\theta_{23} > 45^o$ or $< 45^o$?

- Absolute mass of neutrino

- Majorana or not

Neutrino oscillation probability ~ ν_μ to ν_e oscillation

$$
\begin{aligned}
P(\nu_\mu \to \nu_e) = \; & 4C_{13}^2 S_{13}^2 S_{23}^2 \cdot \sin^2\Delta_{31} \\
& +8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21} \\
& -8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \cdot \sin\Delta_{32} \cdot \sin\Delta_{31} \cdot \sin\Delta_{21} \\
& +4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos\delta) \cdot \sin^2\Delta_{21} \\
& -8C_{13}^2 S_{13}^2 S_{23}^2 \cdot \frac{aL}{4E_\nu} (1 - 2S_{13}^2) \cdot \cos\Delta_{32} \cdot \sin\Delta_{31} \\
& +8C_{13}^2 S_{13}^2 S_{23}^2 \frac{a}{\Delta m_{31}^2} (1 - 2S_{13}^2) \cdot \sin^2\Delta_{31},
\end{aligned}
$$

θ_{13} Leading term

CPV

$$\Delta_{ij} \equiv \Delta m_{ij}^2 \, L/4E_\nu$$
$$a = 2\sqrt{2} G_F n_e E_\nu$$

For anti neutrinos,

$a \to -a$, $\delta \to -\delta$

Now, θ_{13} is known to be (quite) large.

There are chances to observe the contributions from ***mass hierarchy*** and ***CPV (δ)*** !

Use as much neutrino sources as possible
~ Accelerator, Atmospheric, Solar, Super Nova, Astrophysical…

Next generation of experiment ~ requirements

Finite value of θ_{13}

~ Possible to study CP violation, mass hierarchy

Start new experiment as soon as possible

~ with well established and understood detector

Required performance of the detector

Need to be comparable or better than SK

- Particle identification
  - e / μ separation ~ 99% or higher
  - π^0 rejection ***(J-PARC ν beam)*** 95% or higher
- Virtex resolution ~30cm **(500 MeV/c e / μ)**
  ~90cm **(10 MeV e)**
- Energy resolution ~5% **(500MeV/c μ)**
  ~20% **(10 MeV e)**
- Decay electron tagging ~98% **(500 MeV/c μ^+)**
- Wide energy coverage several MeV ~ TeV

Hyper Kamiokande project

Study 1) Accelerator neutrinos from J-PARC,
2) Atmospheric, Solar, Super Nova, cosmic neutrinos,
3) Nucleon decay

with 1M ton Water Cherenkov detector ***"Hyper Kammiokande".***

(Fiducial : ~ 560 kt)

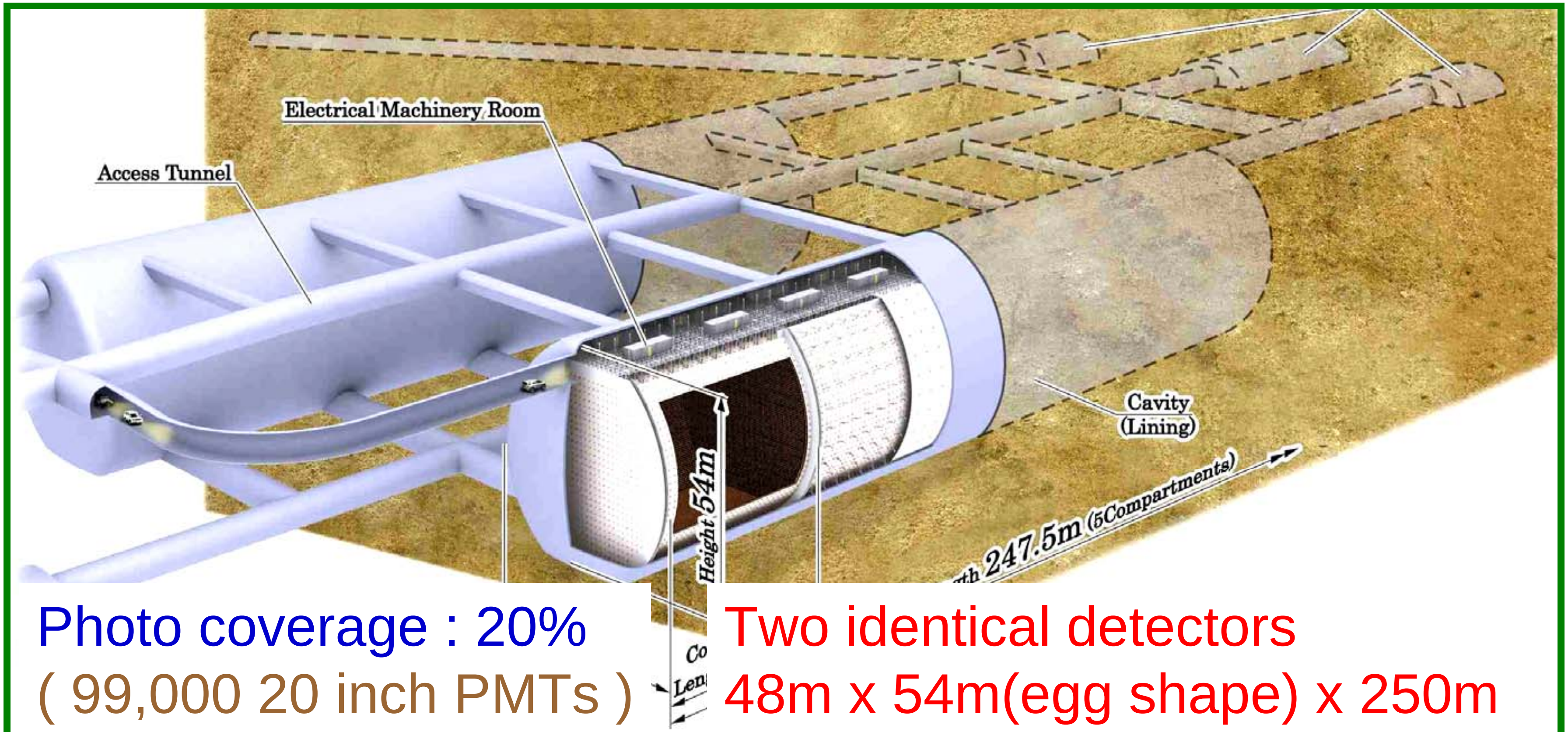


Photo coverage : 20%
(99,000 20 inch PMTs)

Two identical detectors
48m x 54m(egg shape) x 250m

Hyper Kamiokande project

Required performance of the detector

Why SK is not sufficient? ~ Need much higher statistics

→ ***1Mton scale（fid. volume > 500kt) detector***

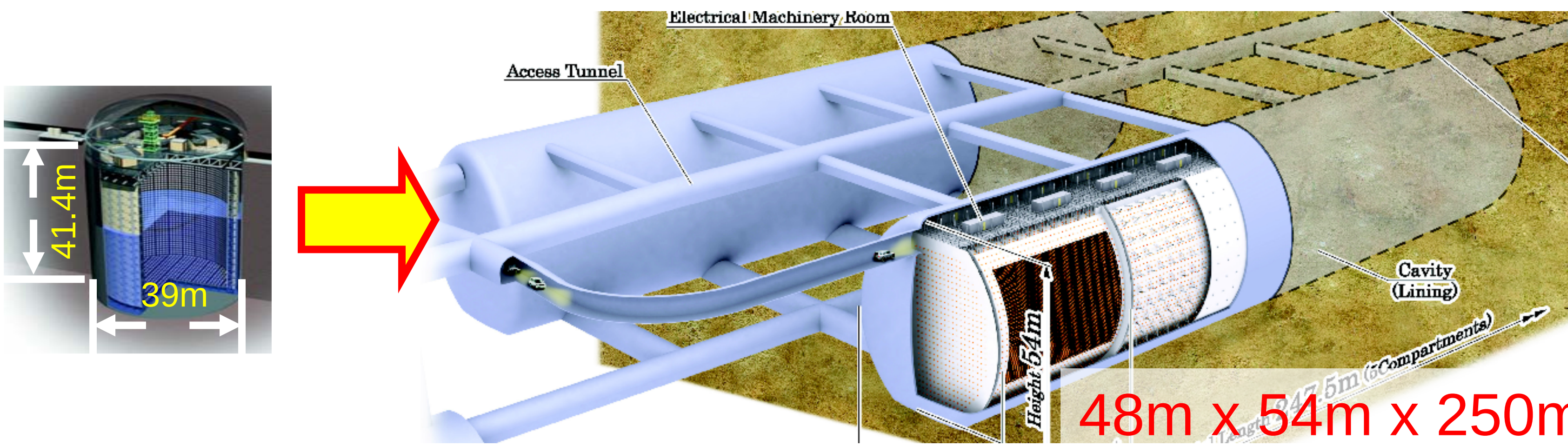
5 SK-like detectors in row

（PMT density ~ SK-II equiv. ） x 2 sets

Maximum utilization of resources and experiences in SK

- Possible to achieve the requirements
- **Realistic evaluation** of the various sensitivities

SK : Fiducial 22.5 kton HK : Fiducial 560 kton **~ 25 x SK**

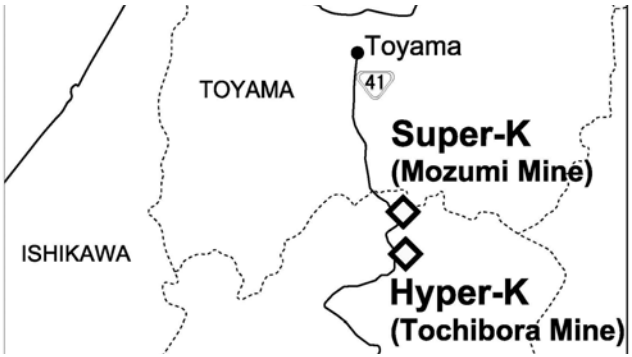


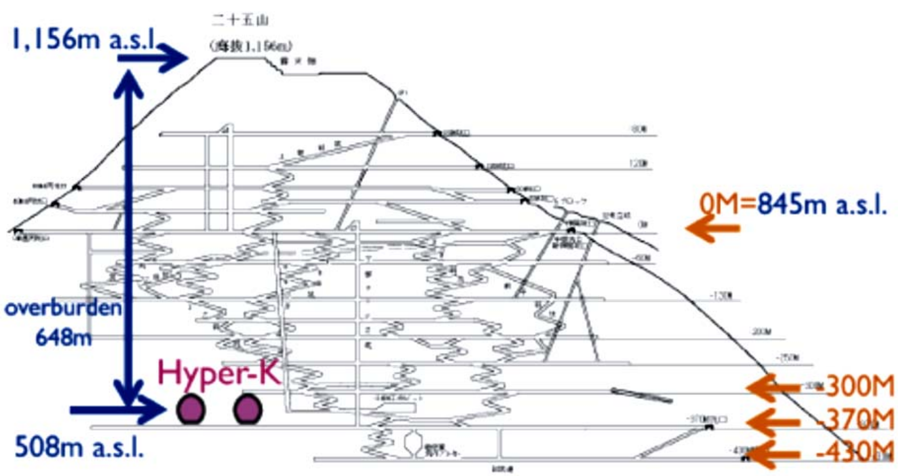
Hyper Kamiokande project

Is it possible to construct such gigantic detectors?

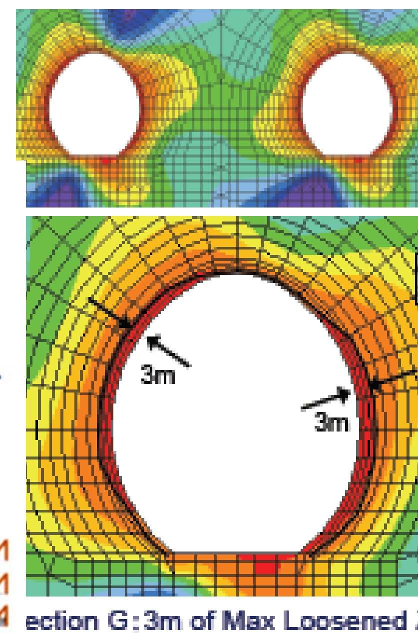
Geological survey and design of the cavern is now under the way.

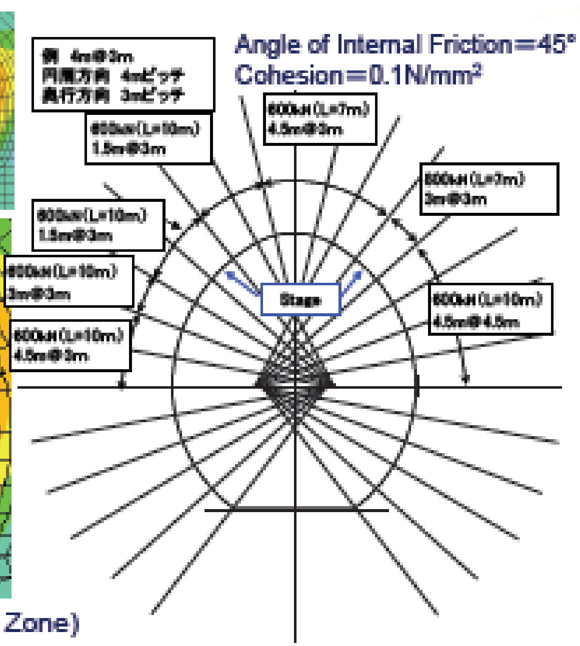
Candidate site :
Tochibora mine in Kamioka





Design of the cavern and its supporting structures

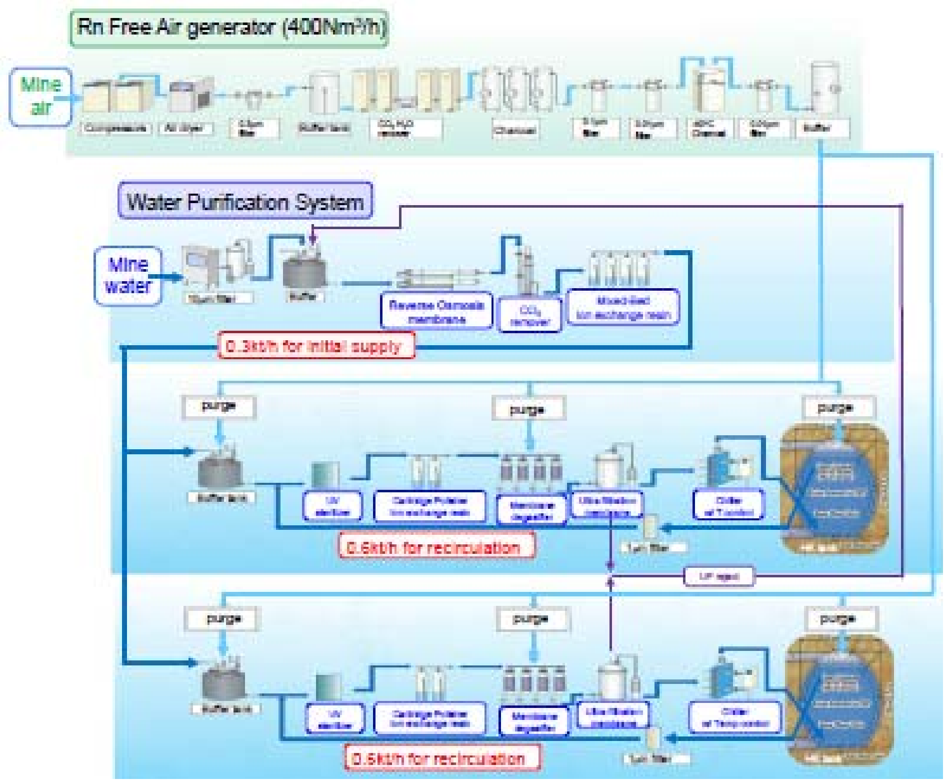




➡ Seems to be possible to have large enough cavern

Hyper Kamiokande project

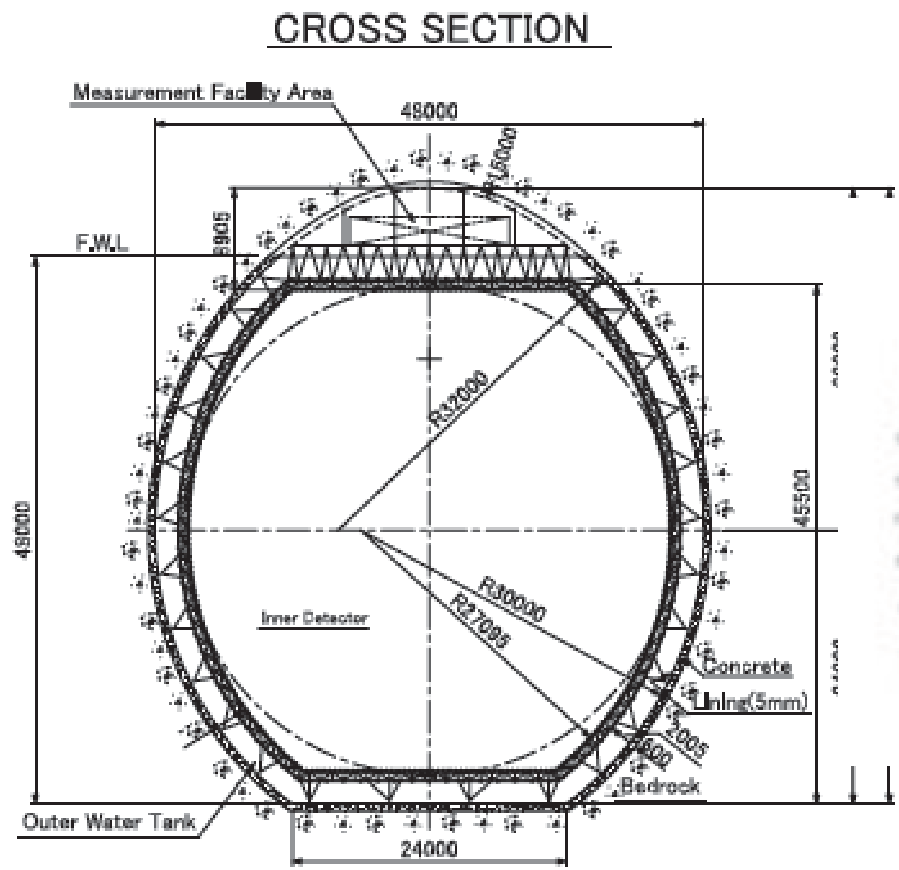
Schematic diagram of water purification system for HK detector



Water circulation rate
~ 600 ton / hour / detector
(> x 10 compared to SK)

Design of the detector structure

Incl. PMT supports



➡ ***Detector seems to be feasible.***

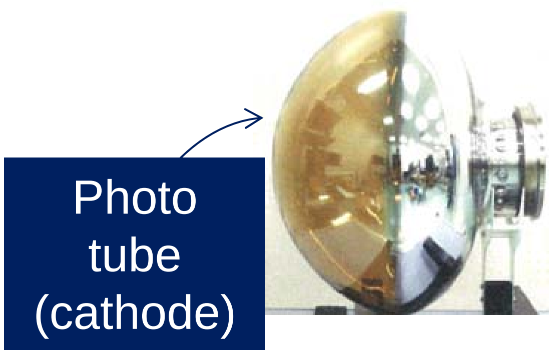
Status of detector components R&D

- Photo sensor

One candidate : Hybrid Photon Detector (HPD) from HPK

8 inch HPD is in testing

20 inch HPD is under development



- Front end electronics

Design is just started.

Baseline design:

Revised version of Current SK frontend. (QTC + TDC)

In the water?

Easier cable handling

Smaller signal degradation

(Start R&D soon.)

Also considering 20 inch conventional PMT.

Hyper Kamiokande project

What we can do with Hyper-Kamiokande detector?

- **Neutrino oscillation ~ Beyond the standard model**

  Accelerator neutrinos from J-PARC

  and atmospheric neutrinos

  - CP violation in lepton sector
  - Mass hierarchy $\Delta m_{23} > 0$ or < 0 ?
  - Precise measurements of ν osc. parameters

- **Nucleon decay ~ Direct confirmation of GUT**
- **Super Novae neutrinos**

  Neutrinos from Super Nova burst

  - Mechanism of Super Nova burst
  - Neutrino mass determination, hierarchy

  Supernova remnant neutrinos

  - Nuclear synthesis

- **Solar neutrinos, Point source searches**

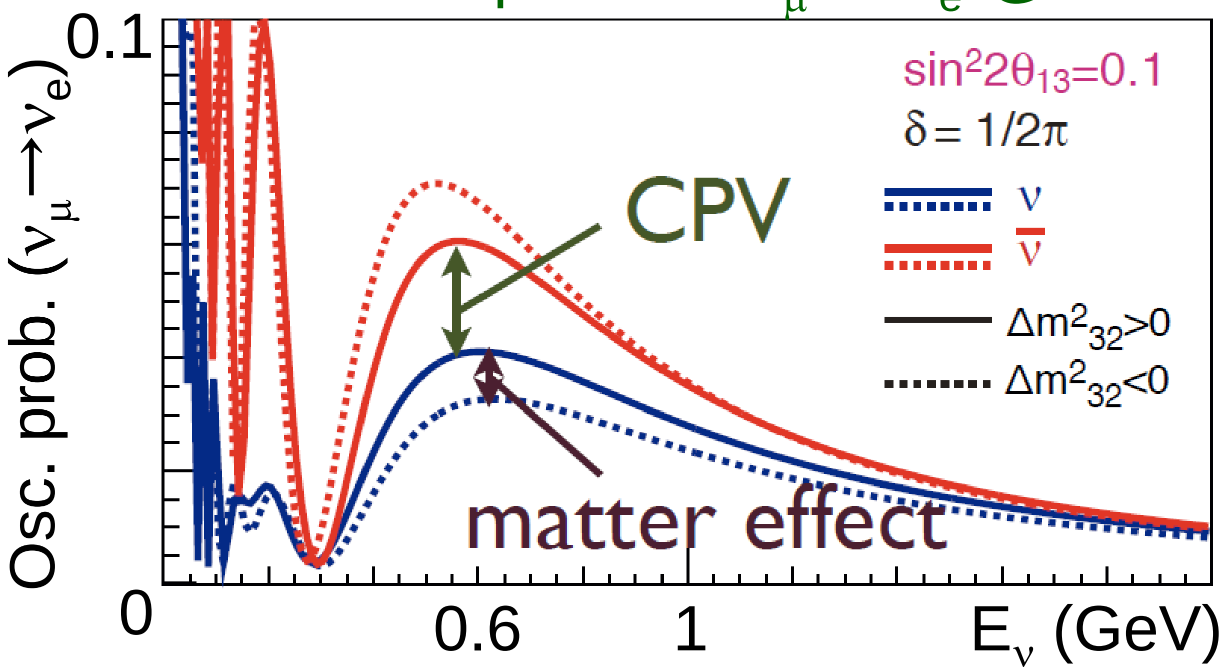
Neutrino physics in HK 1 ~ Determination of CP δ

CP-non conservation term in osc. prob. $\propto$ $\sin\theta_{13}\sin\delta$

(**sign of δ for anti-neutrino is different from neutrino**)

- $\sin^2 2\theta_{13} \sim 0.1$ → Next target : **Study of CP violation**

Oscillation prob. for $\nu_\mu \rightarrow \nu_e$ @ 295km



$\Delta m^2_{21}=7.6\times10^{-5}eV^2$

$|\Delta m^2_{32}|=2.4\times10^{-3}eV^2$

$\sin^2\theta_{12}=0.31$

$\sin^2\theta_{23}=0.5$

$\rho=2.6g/cm^3$

→ **Huge detector (HK) @ Kamioka**

\+ **Improved J-PARC neutrino beam (≥ 750kW)**

Measure δ by comparing oscillations of ν and $\bar{\nu}$.

Neutrino physics in HK 1 ~ Determination of CP δ

Neutrino beam from J-PARC (0.75 MW)

10 yrs of running (ν 3 yrs. + $\bar{\nu}$ 7 yrs., 1 yr $\equiv 10^7$ sec.)

If $\sin^2 2\theta_{13} = 0.1$,

Expected # of events:

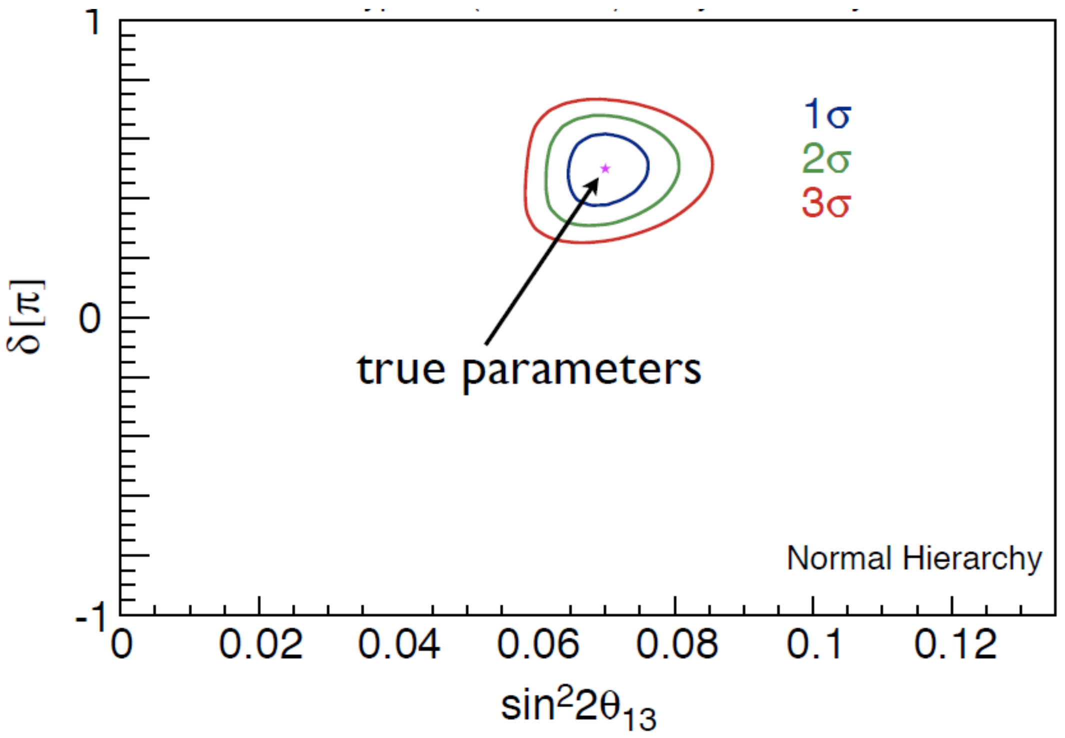
$\nu_\mu \rightarrow \nu_e$ oscillation

~ 3600 events / 3 yrs.

$\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillation

~ 2350 events / 7 yrs.

Use reconstructed energy spectra of ν and $\bar{\nu}$



Neutrino physics in HK 1 ~ Determination of CP δ

Neutrino beam from J-PARC (0.75 MW)

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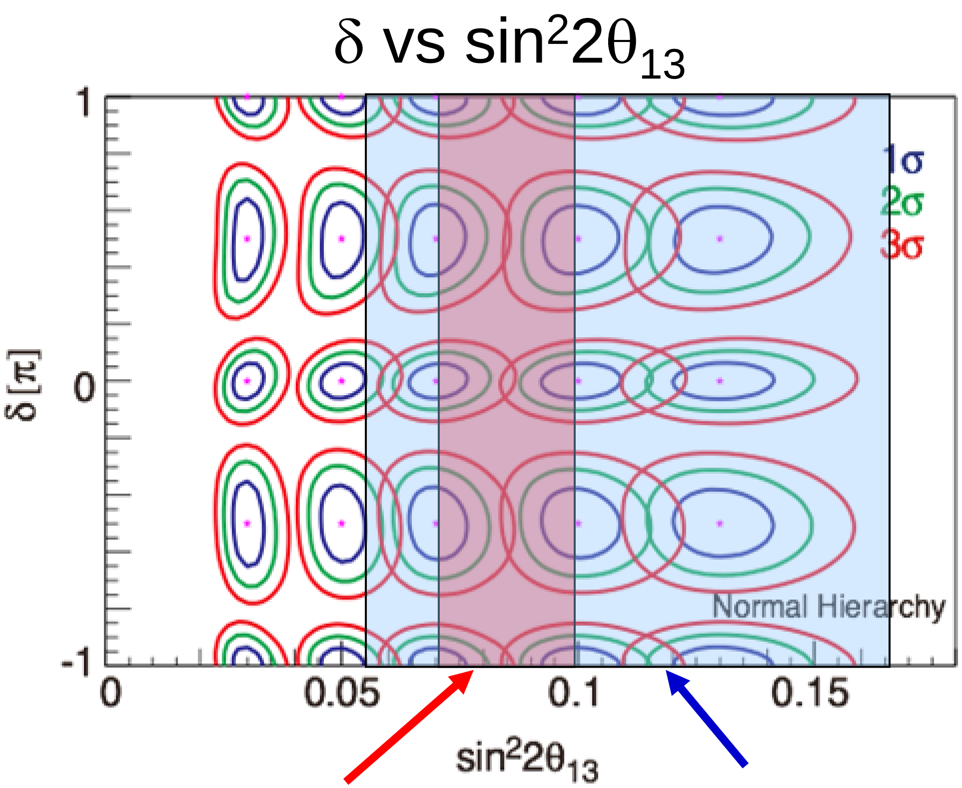
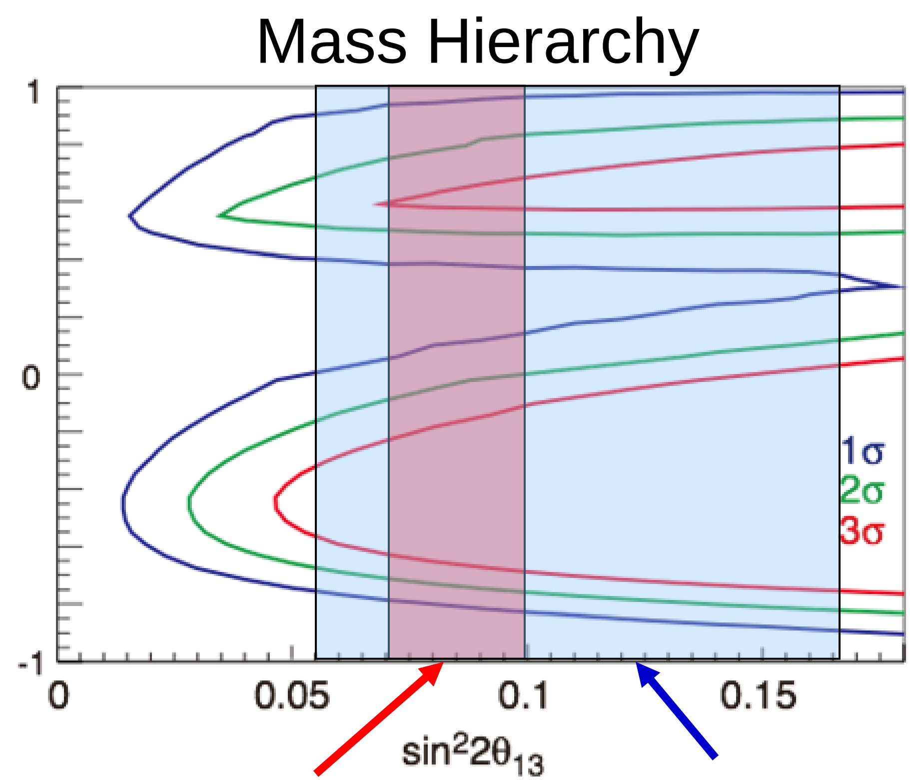




- CP phase parameter precision (w/ hierarchy info.) ＜18°
- Chance to determine the mass hierarchy ~ 43%

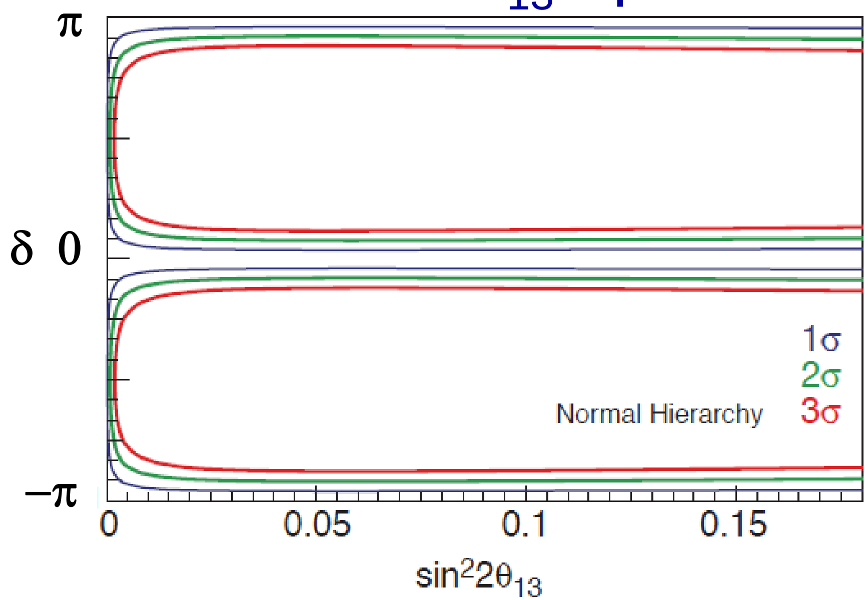
Neutrino physics in HK #1 ~ Determination of CP δ

Neutrino beam from J-PARC (0.75 MW)

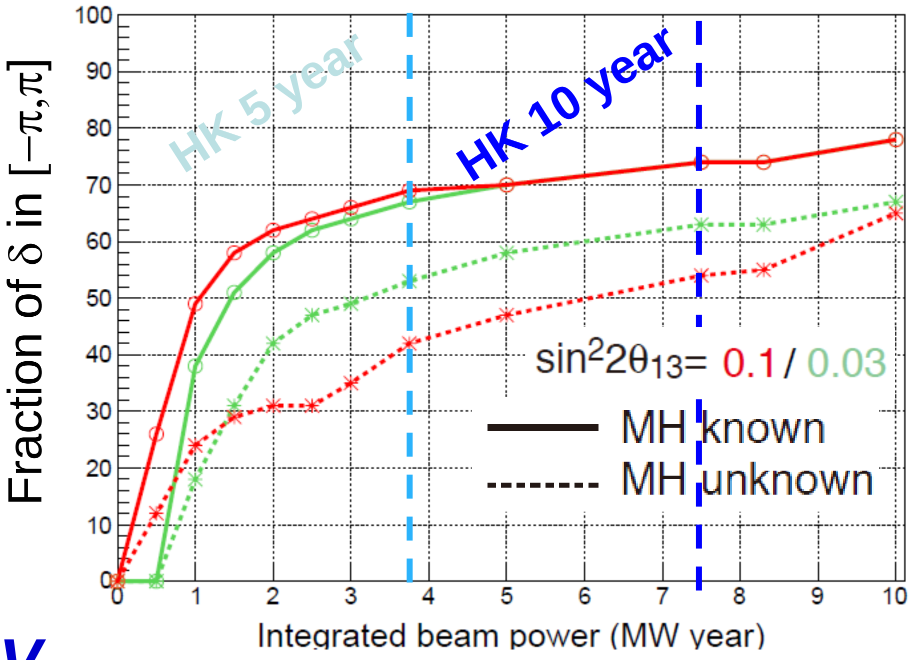
10 yrs of running (ν 3 yrs. + $\bar{\nu}$ 7 yrs., 1 yr ≡ 10^7 sec.)

5% systematic error is assumed. (T2K ~ 10%)

δ = 0 exclusion (CPV sensitivity) in true $\delta - \theta_{13}$ space



Chance to observe CP violation >3σ



74% chance to observe CPV

with *10 years* operation ***if MH is known***

(~ 54% if MH is not known)

Neutrino physics in HK #2 ~ Mass hierarchy and θ_{23}

High statistics atmospheric neutrino data

~ Possibility in observing small distortion in ν_e

- Matter effect ~ from mass hierarchy

  Possible ν_e enhancement in several GeV passed through the earth core

- Solar term ~ from θ_{23} octant degeneracy

  Possible ν_e enhancement in sub-GeV

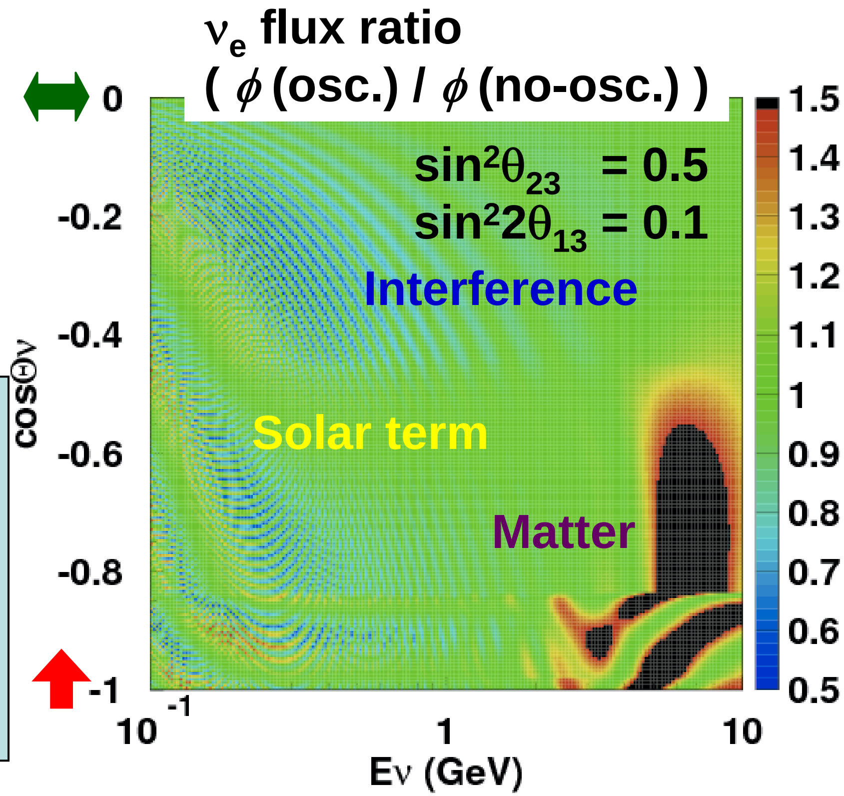
- Interference

  CP phase could be studied.

Difference in # of electron events:

$$\Delta_e \equiv \frac{N_e}{N_e^0} \cong \Delta_1(\theta_{13}) + \Delta_2(\Delta m^2_{12}) + \Delta_3(\theta_{13}, \Delta m^2_{12}, \delta)$$

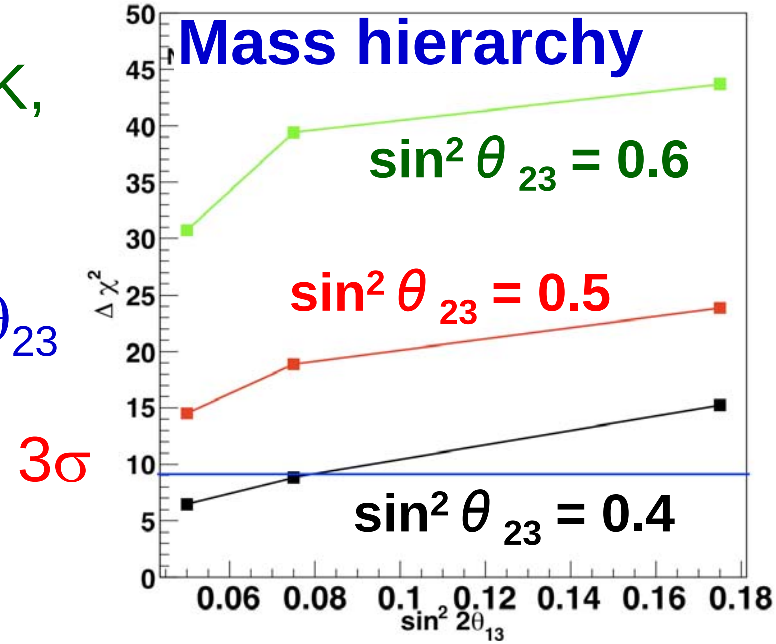
- $\Delta_1(\theta_{13})$ ← **Matter effect**
- $\Delta_2(\Delta m^2_{12})$ ← **Solar term**
- $\Delta_3(\theta_{13}, \Delta m^2_{12}, \delta)$ ← **Interference**

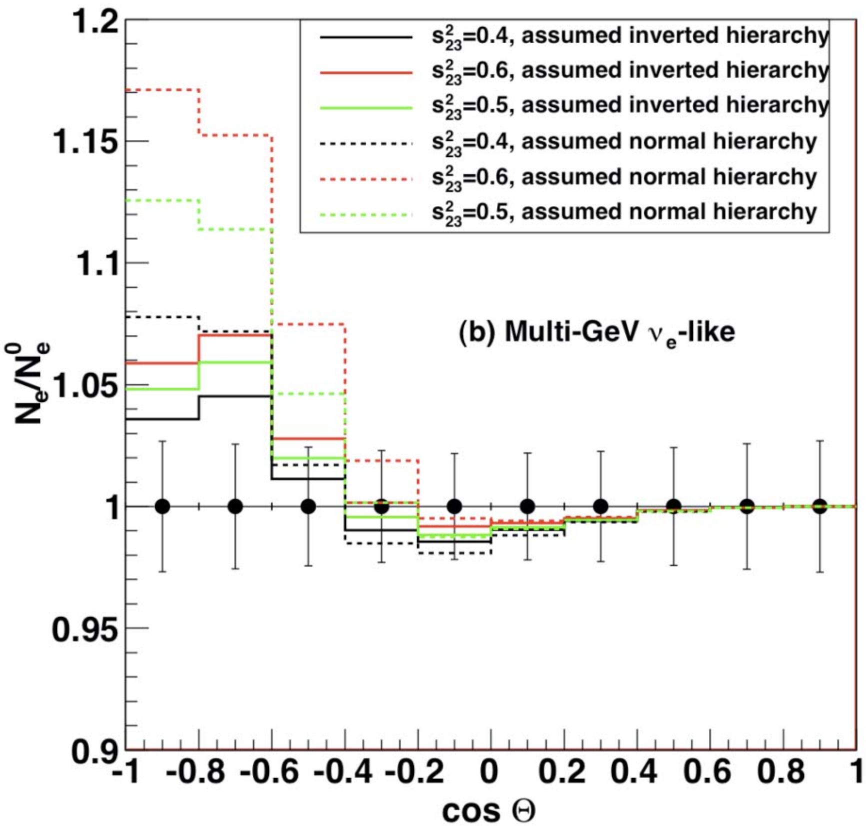


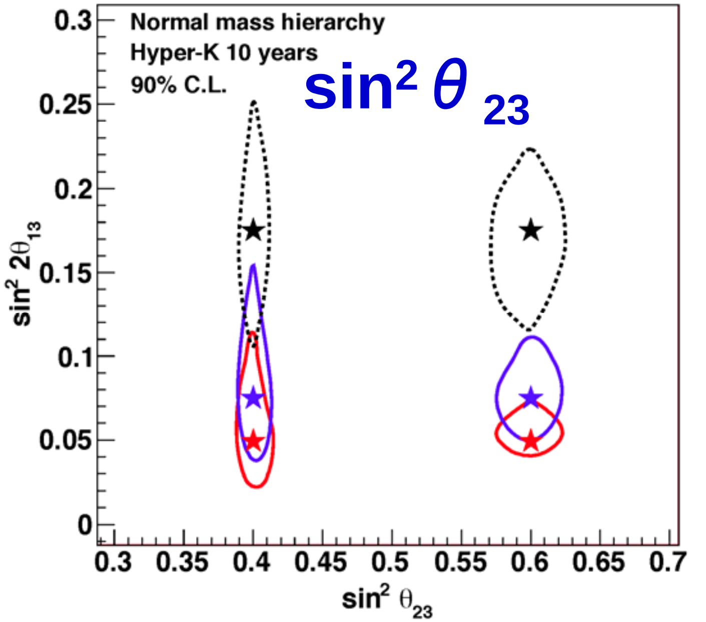
Neutrino physics in HK #2 ~ Mass hierarchy and θ_{23}

With 10 yrs of atmospheric neutrino observation in HK,

possible to study both mass hierarchy and octant of θ_{23}





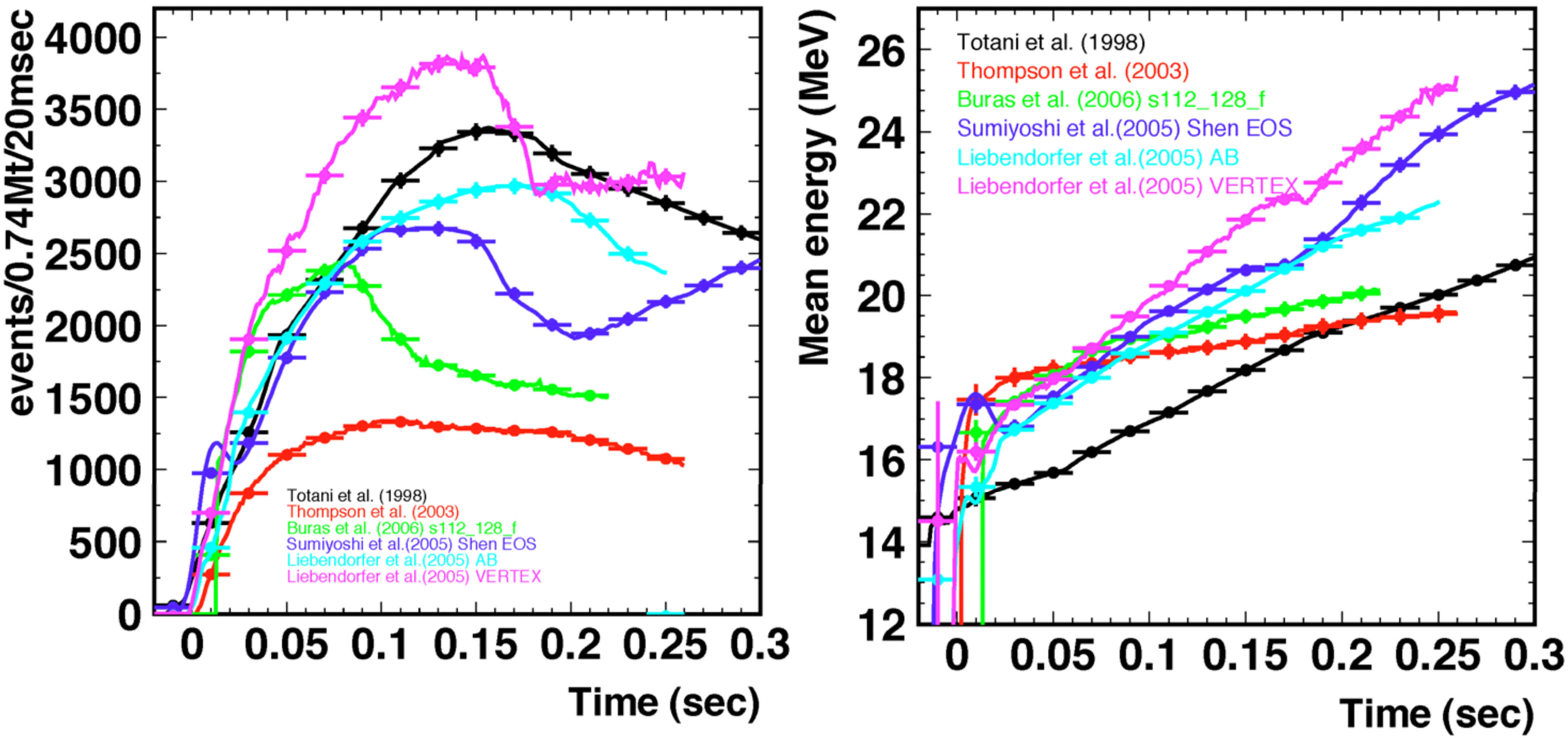


Neutrino physics in HK #3 ~ Super Nova neutrinos

Super nova burst at the galactic center (@10kpc)

Expected # of events : 170,000~260,000

Provide precise information of energy and arrival timing

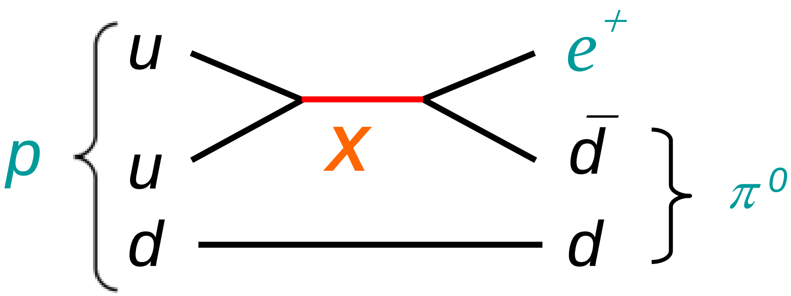


Strong constraints on the models of Super nova bursts

Constraints on neutrino mass with arrival timing distribution.

Nucleon decay in HK ~ Direct confirmation of GUT

$p \rightarrow e^+\pi^0$

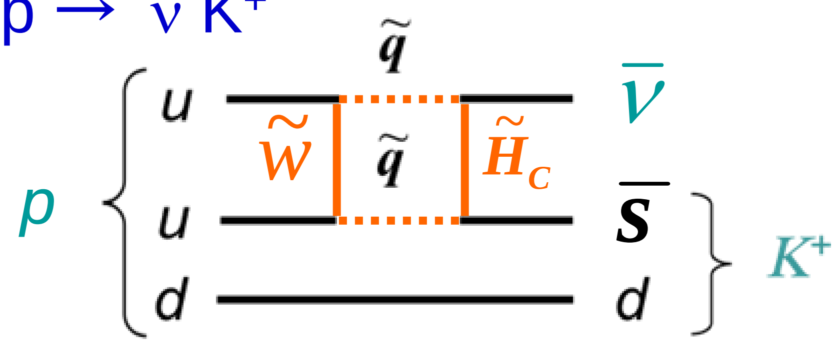


SK : 1.3 x 10^{34}yr

→ HK ~ 1.3 x 10^{35} yr

(90% C.L.)

$p \rightarrow \bar{\nu} K^+$



SK : 4.0 x 10^{33}yr

→ HK ~ 2.5 x 10^{34} yr

(90%CL)

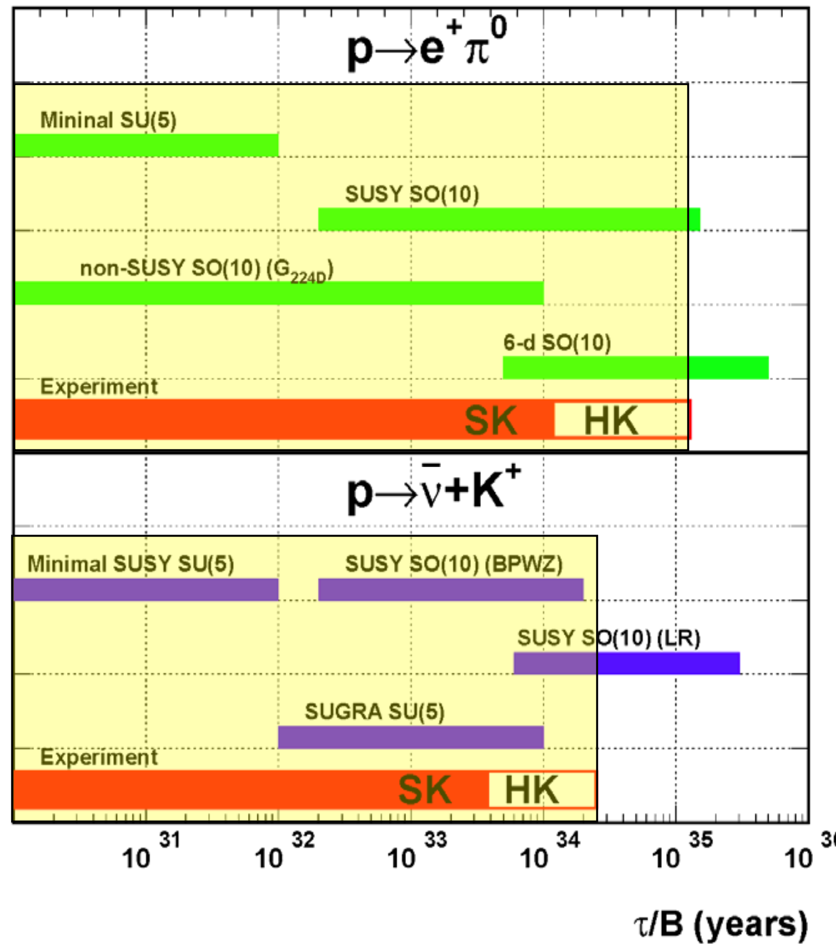
In Super-Kamiokande,

we have collected 0.2Mton·yr of data

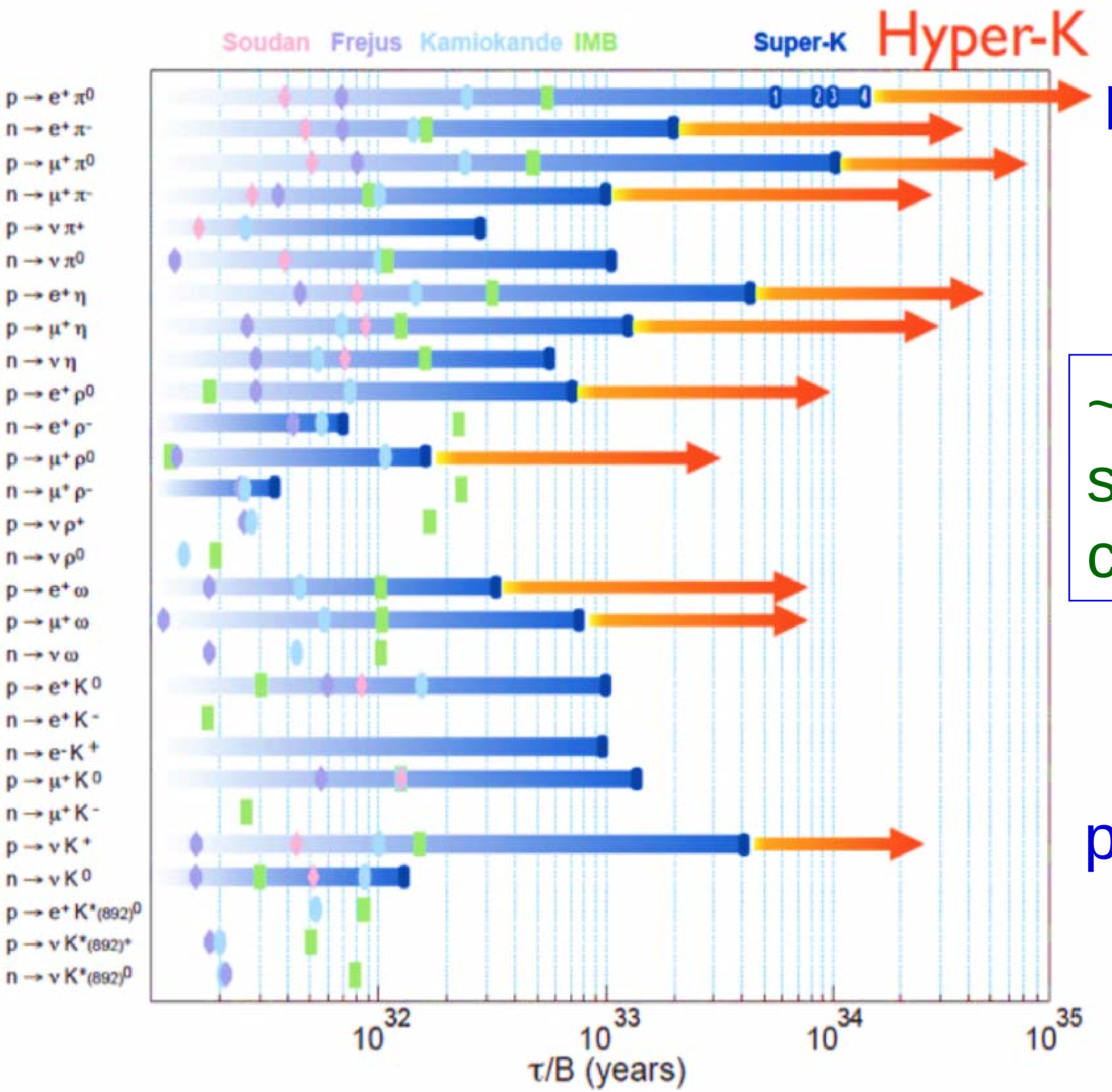
but no indication was observed.

HK can cover

another order of magnitude.



Nucleon decay in HK ~ Direct confirmation of GUT



$p \rightarrow e^+\pi^0$

~ 1.3 x 10^{35} yr

(90% C.L.)

~ 10 times better sensitivities compared to SK!

$p \rightarrow \bar{\nu} K^+$

~ 2.5 x 10^{34} yr

(90%CL)

Hyper-Kamiokande working group meeting
August 21 ~ 23, 2012 at Kavli IPMU, Univ. of Tokyo.
(Kashiwa, Chiba, Japan)

http://indico.ipmu.jp/indico/conferenceDisplay.py?confId=7

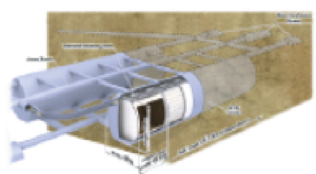
Open Meeting for the Hyper-Kamiokande Project

21-23 August 2012 *Kavli Institute for the Physics and Mathematics of the Universe (Kavli IPMU), The University of Tokyo*
Asia/Tokyo timezone

Overview
Important Dates
Call for Abstracts
- View my abstracts
- Submit a new abstract

Timetable
Contribution List
Registration
- Registration Form

Access
Accommodation



Overview

We will hold an International Open Working Group Meeting for the Hyper-Kamiokande project. Hyper-K, which we are currently developing, is designed to be the next decade's flagship experiment for the study of neutrino oscillations, nucleon decays, and astrophysical neutrinos.

The goal of this meeting is to discuss the physics potentials of Hyper-K, the design of the detector, and necessary R&D items including:

- cavern excavation
- tank liner material and its design
- photo-sensors and their support structure
- DAQ electronics and computers
- calibration systems
- water purification systems
- software development, and so on.

Participants are encouraged to submit abstracts for talks in which to present their individual interests in topics related to Hyper-K, as well as discuss possible future contributions to the project.

Summary

Letter of Intent : arXiv:1109.3262 [hep-ex]

Hyper Kamiokande Project

Study physics beyond the standard model
with new 1 M ton water Cherenkov detector
based on the experience in Super-Kamiokande.

- Accelerator neutrinos from J-PARC
  and atmospheric neutrinos
  - CP violation in lepton sector
  - Mass hierarchy
  - Precise measurements of oscillation parameters.
- Nucleon decay ~ direct confirmation of GUT
- Super nova neutrino bursts
  - Mechanism of supernova burst
  - Neutrino mass measurements and hierarchy

Hyper-Kamiokande working group meeting
August 21 ~ 23, 2012 at Kavli IPMU, Univ. of Tokyo.

Fin.