May 30, 2001
@JHF-SK nu

JHF-Kamioka Neutrino experiment

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1. Overview of the experiment
2. Physics sensitivity in Phase-I
3. Physics sensitivity in Phase-II
4. Summary and Conclusion

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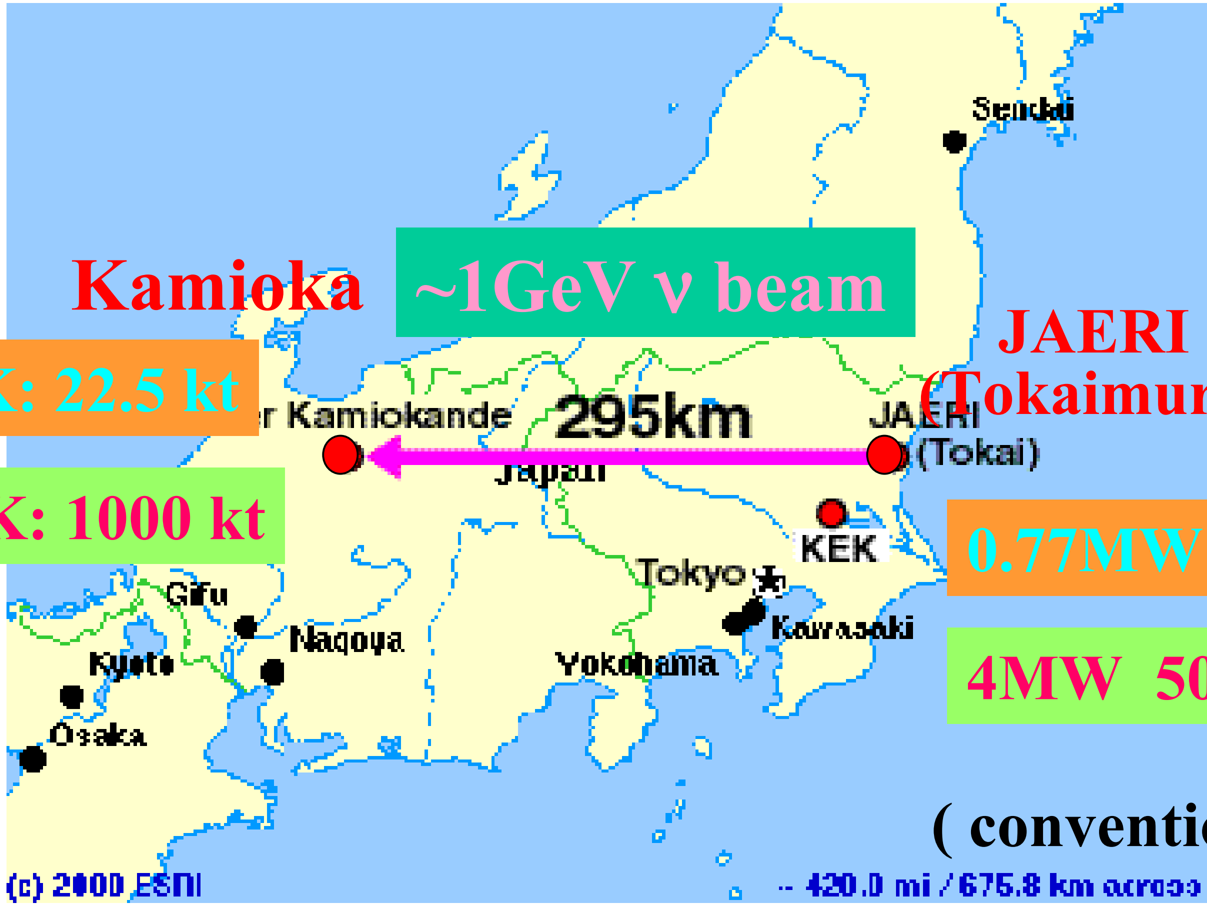
15,5

1.Overview of the experiment

(expect to start in 2007)

Exist

approved



Kamioka

~1GeV ν beam

JAERI (Tokaimura)

Super-K: 22.5 kt

Hyper-K: 1000 kt

0.77MW 50 GeV PS

4MW 50 GeV PS

(conventional ν beam)

Phase-I (0.77MW + Super-K)

Phase-II (4MW+Hyper-K) ~ Phase-I **× 200**

JHF-Kamioka neutrino project

- L=295km, Eν=0.5~2 GeV
  - match to the Water Cherenkov detector (SK exists)
    - generally easy to build a larger detector
    - less NC π^0 background to $\nu_\mu \rightarrow \nu_e$
    - good ν energy reconstruction by QE interaction
    - good particle ID
  - small matter effect (difficult to see the sign of Δm_{23}^2, but easier to look for CP violation.)
  - match to a size of Japan with the existing facilities

GOAL: detailed study of ν oscillation phenomena

Standard scenario:

NMS (Maki-Nakagawa-Sakata) matrix:

$$U=\begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23}-c_{12}s_{13}s_{23}e^{-i\delta} & c_{12}c_{23}-s_{12}s_{13}s_{23}e^{-i\delta} & c_{13}s_{23} \\ s_{12}s_{23}-c_{12}s_{13}c_{23}e^{-i\delta} & -c_{12}s_{23}-s_{12}s_{13}c_{23}e^{-i\delta} & c_{13}c_{23} \end{pmatrix}$$

$$s_{ij} = \sin\theta_{ij}, c_{ij} = \cos\theta_{ij}, \Delta m_{ij}^2 = \Delta m_i^2 - \Delta m_j^2$$

	Δm_{12}^2	Δm_{23}^2	θ_{12}	θ_{23}	θ_{13}	δ
solar ν and reactor ν	O		O			
LBL and atm. ν		O		O	O	
Future LBL	Δ	O(*sign*)	Δ	O	O	O

ν oscillation

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{23} \bullet \cos^4 \theta_{13} \bullet \sin^2\left(\frac{1.27\,\Delta m_{23}^2\left[eV^2\right] \bullet L\left[km\right]}{E\left[GeV\right]}\right) - P(\nu_\mu \to \nu_e)$$

$$P(\nu_\mu \to \nu_e) = \sin^2 2\theta_{13} \bullet \sin^2 \theta_{13} \bullet \sin^2\left(\frac{1.27\,\Delta m_{23}^2\left[eV^2\right] \bullet L\left[km\right]}{E\left[GeV\right]}\right)$$

at $\theta_{23} \sim \pi/4$ and $\theta_{13} \sim 0$

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta_{\mu\tau} \bullet \sin^2\left(\frac{1.27\,\Delta m_{23}^2\left[eV^2\right] \bullet L\left[km\right]}{E\left[GeV\right]}\right) - P(\nu_\mu \to \nu_e)$$

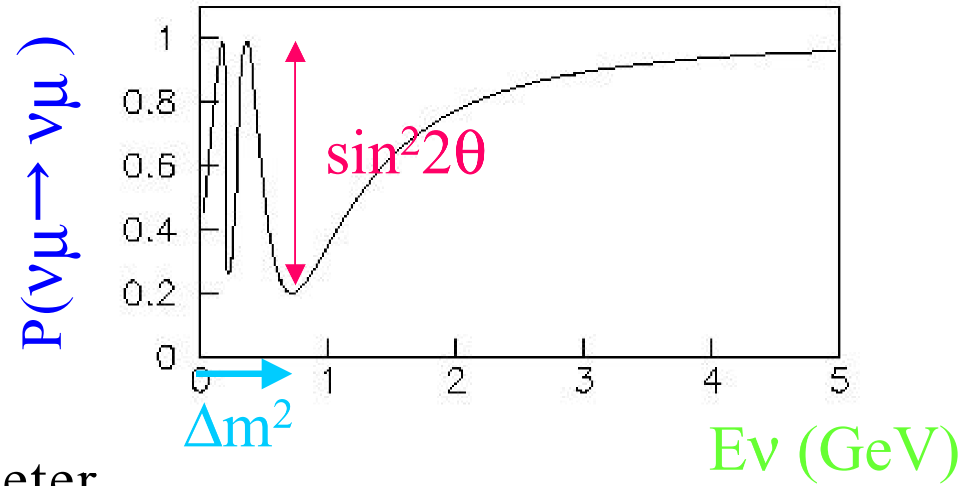
$$P(\nu_\mu \to \nu_e) = \sin^2 2\theta_{e\mu} \bullet \sin^2\left(\frac{1.27\,\Delta m_{23}^2\left[eV^2\right] \bullet L\left[km\right]}{E\left[GeV\right]}\right)$$

$$\sin^2 2\theta_{\mu\tau} \approx \sin^2 2\theta_{23}, \sin^2 2\theta_{e\mu} \approx \frac{1}{2}\sin^2 2\theta_{13} \approx 2\left|U_{e3}\right|^2$$

Δm_{23}^2 and θ_{23} measurement

$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \cos^4\theta_{13} \sin^2 2\theta_{23} \sin^2(1.27\ \Delta m_{23}^2\ L/E)$

~1



- **Δm_{23}^2**
  - Mass is a basic parameter.
  - If $m_3 >> m_2$, the measurement is the mass itself which indicates a scale at high energy. <= GUT
- **θ_{23}**
  - $\theta_{23} = \pi/4$ or NOT (several predictions from GUT)
    - $\sin^2 2\theta = 0.93$ (Yanagida and Fukugita)
      $= 0.81\text{-}0.96$ (J. Pati, hep-ph/0005095)

θ_{13} measurement

$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2(1.27\ \Delta m_{23}^2\ L/E)$

- A mixing angle between 1st and 3rd generation in MNS.
  - θ_{13} may be just below the CHOOZ limit, and $\nu_\mu \rightarrow \nu_e$ is waiting to be discovered.

    $\sin^2 2\theta_{13}$ = 0.014 (SU(5)-GUT, hep-ph/0007254)

    = 0.01-0.09 if LMA (PRL84, 3535 (2000))

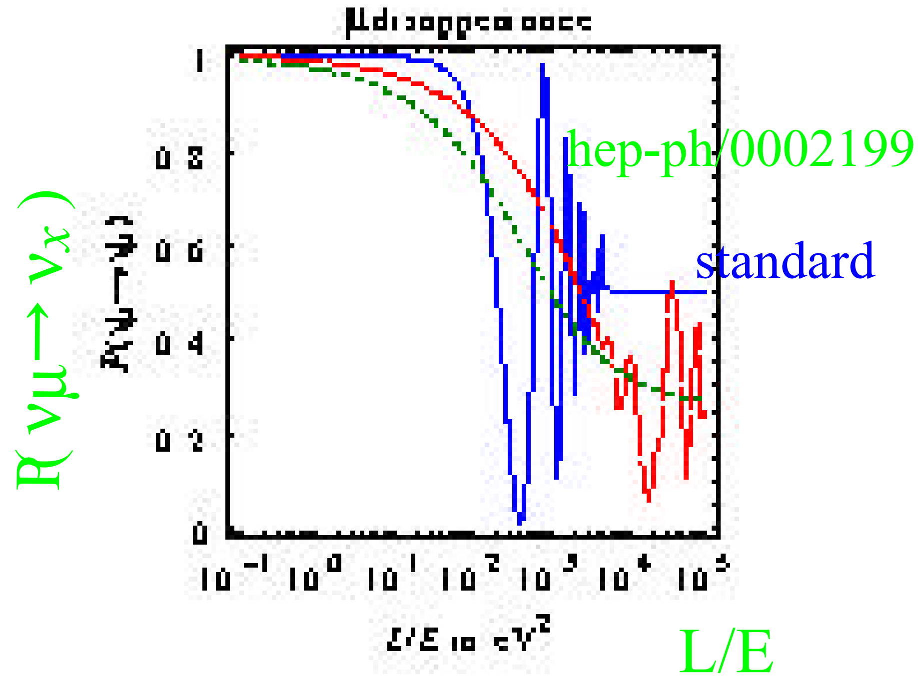
    ~ 0

- A discovery of $\nu_\mu \rightarrow \nu_e$ can open the new window to study CP violation in this mode.

  may be a source of baryogenesis in the universe.

Non standard ν oscillation

- Large Extra Dimension

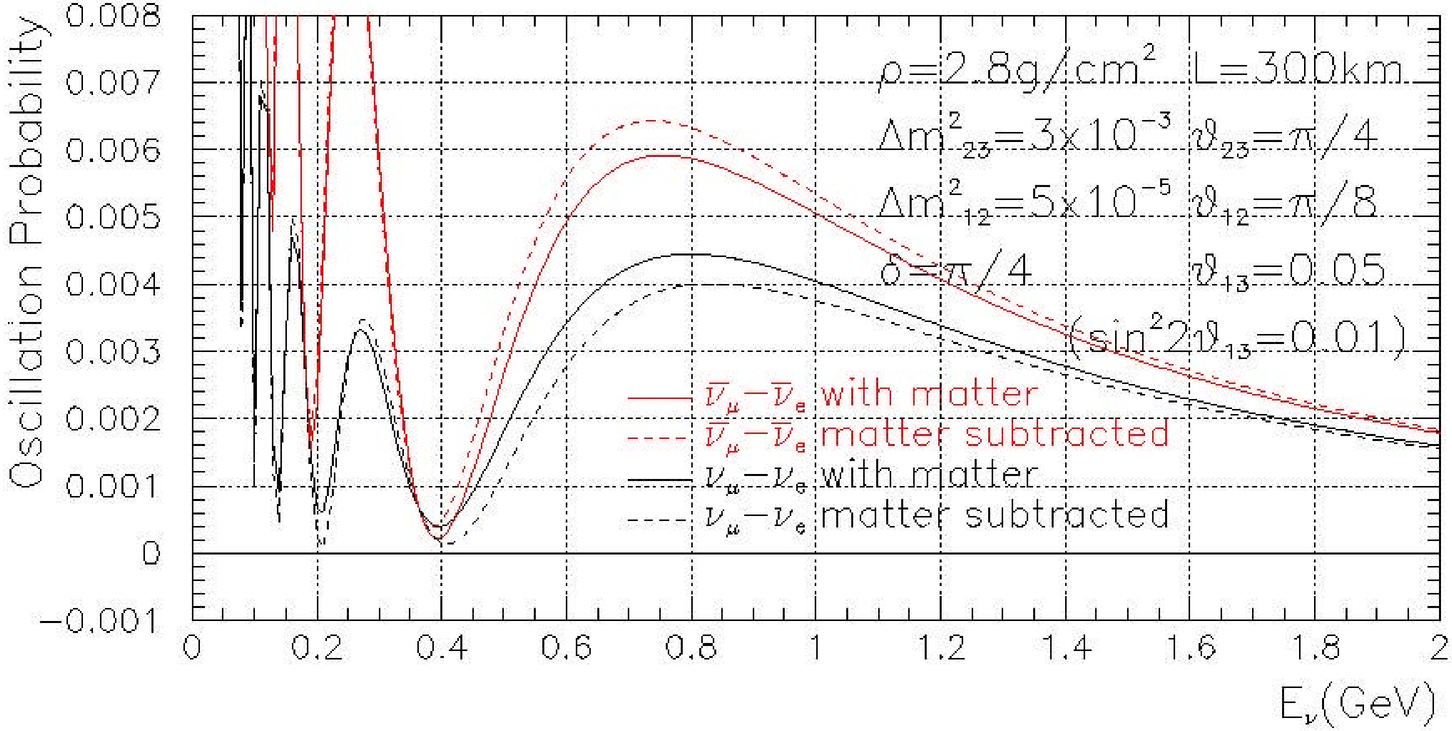


- A sterile neutrino (LSND result? 3 or 4 ν's)
- non standard CP violation of $\nu_\mu \to \nu_\tau$.
  - (see Yasuda-san's talk at PA08d (neutrino), ICHEP 2000)
- Any other unexpected phenomena

CP violation in ν oscillation

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \approx \frac{\Delta m_{12}{}^2 L}{4E_\nu} \bullet \frac{\sin 2\theta_{12}}{\sin\theta_{13}} \bullet \sin\delta$$

L=295km : small matter effect   Eν~1 GeV : large CP asymmetry

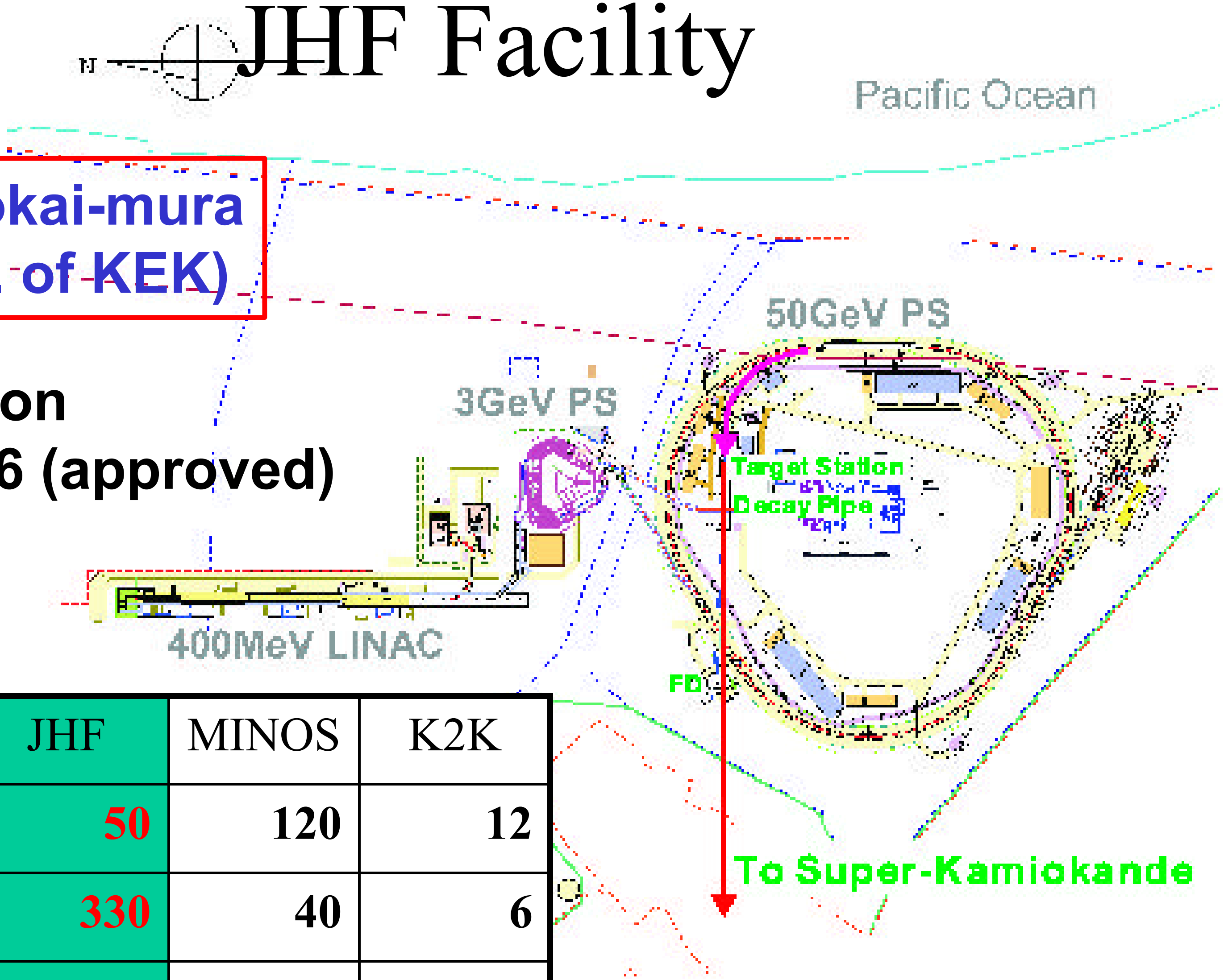


•If LSND is true, CP violation may be much larger than we expect.

JHF Facility

JAERI@Tokai-mura (60km N.E. of KEK)

Construction 2001～2006 (approved)



	JHF	MINOS	K2K
E(GeV)	50	120	12
Int.(10^{12}ppp)	330	40	6
Rate(Hz)	0.29	0.53	0.45
Power(MW)	0.77	0.41	0.0052

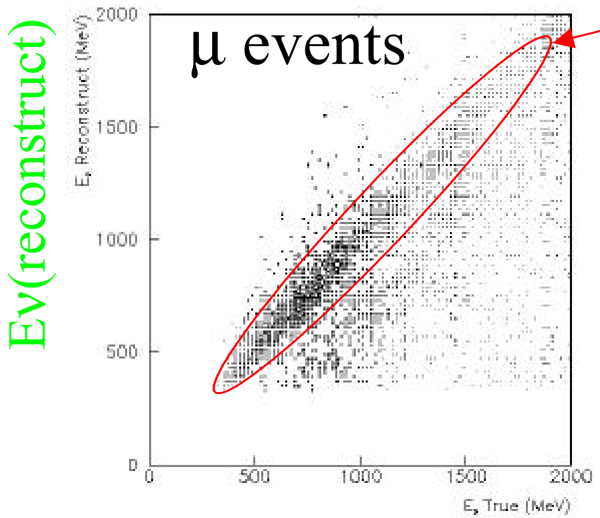
10^{21}POT(130day)≡ "1 year"

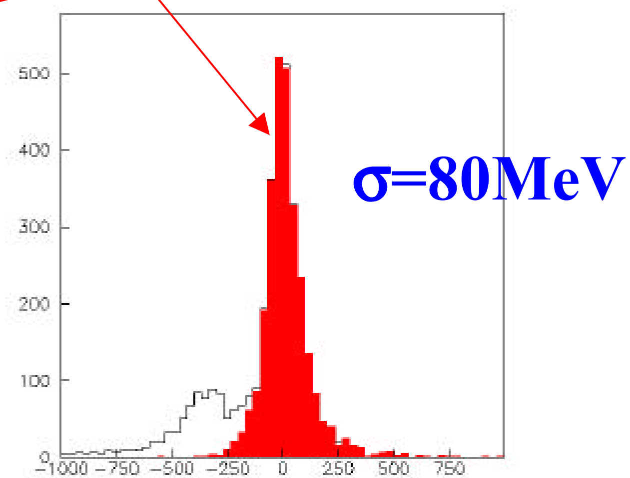
ν beam at JHF

- **Principle**
  - **Intense Narrow Band Beam : two methods.**
  - Beam energy is tuned to be at the oscillation maximum.
    - High sensitivity
    - Less background
  - ~1 GeV beam energy for **Quasi-elastic** interaction.

$\Delta m^2 = 1.6\sim4\text{x}10^{-3}\text{eV}^2$

$E_\nu = 0.4\sim1.0\text{GeV}$



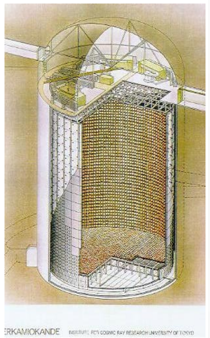


ν detector

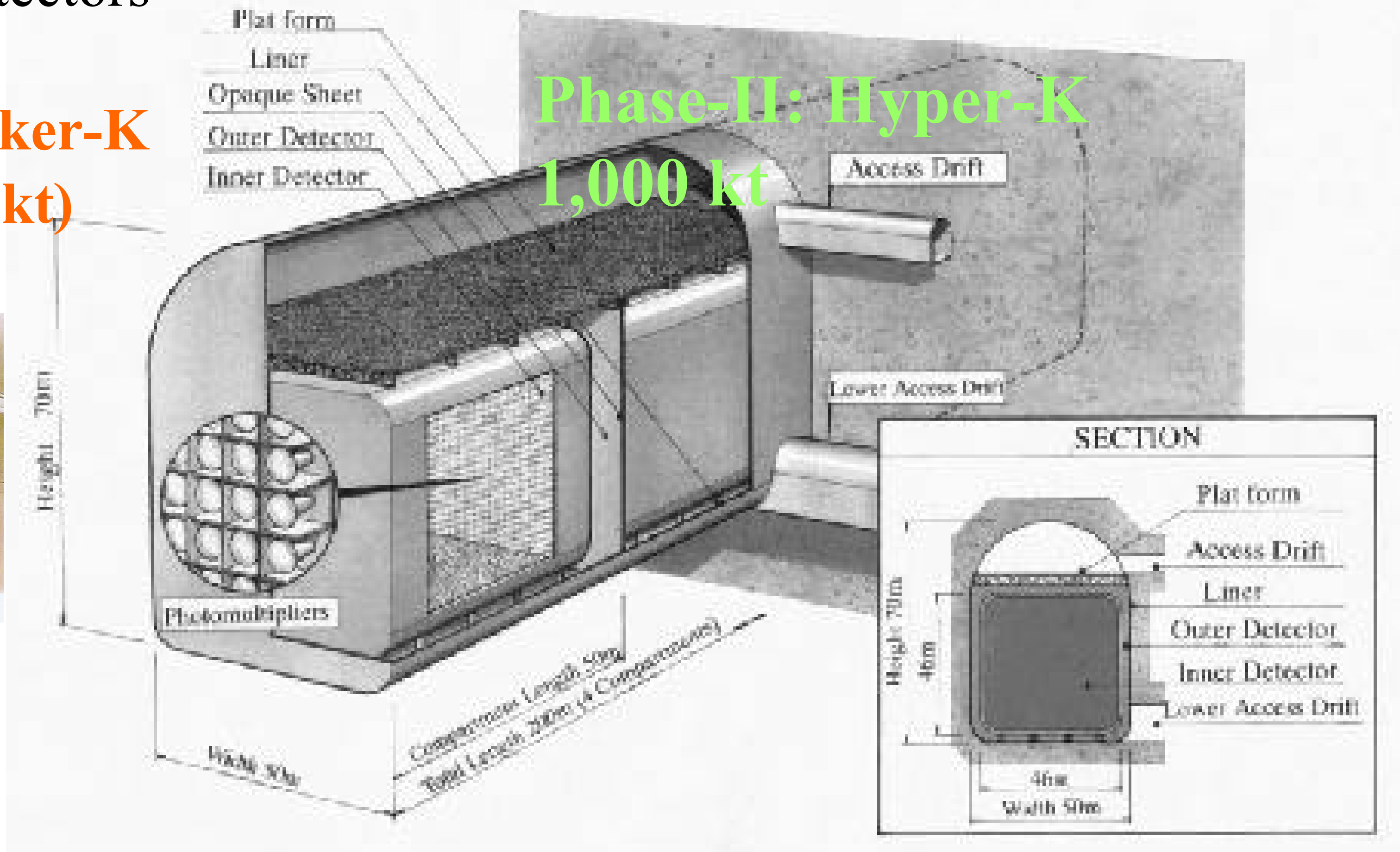
- Near ν detector: discussion tomorrow

- Far ν detectors

Phase-I: Suker-K
22.5kt (50kt)



Phase-II: Hyper-K
1,000 kt



3. Physics sensitivity in Phase-I

5years running (from 2007)

→ precise measurement of Δm_{23}^2, θ_{23} and θ_{13}

- $\nu_\mu \to \nu_\mu$ (Δm_{23}^2, θ_{23})
- $\nu_\mu \to \nu_e$ (θ_{13}, open window for CP study)
- $\nu_\mu \to \nu_\tau$ w/ NC interactions. (confirmation)
- stringent limit on the non-oscillation scenario and the existence of ν_s.

Sensitivity (goal):

$\delta \sin^2 2\theta_{23} < 0.01$

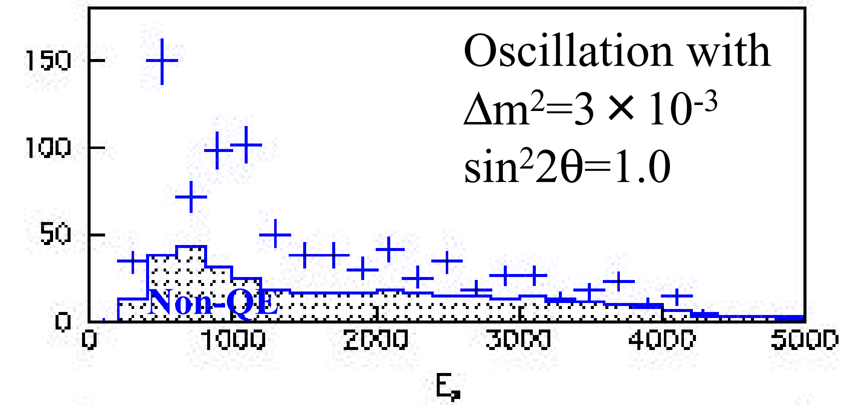
$\sin^2 2\theta_{13} < 6 \times 10^{-3}$ (90% CL)

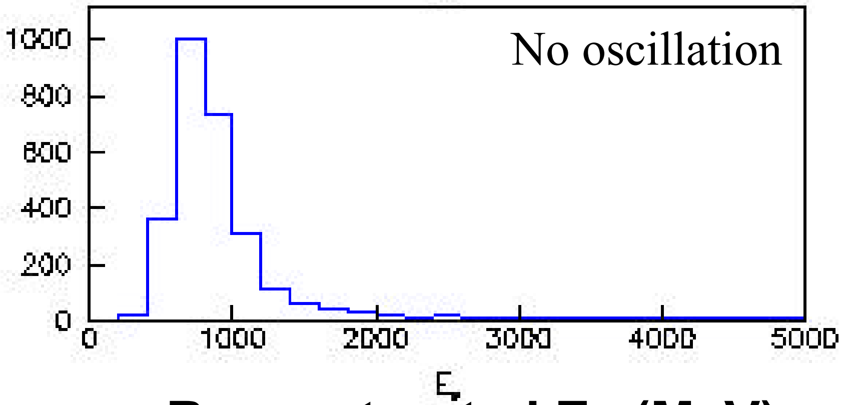
$\delta \Delta m_{23}^2 < 1 \times 10^{-4} \mathrm{eV}^2$

at ($\sin^2 2\theta = 1.0$, $\Delta m^2 = 3.2 \times 10^{-3} \mathrm{eV}^2$)

ν_μ disappearance

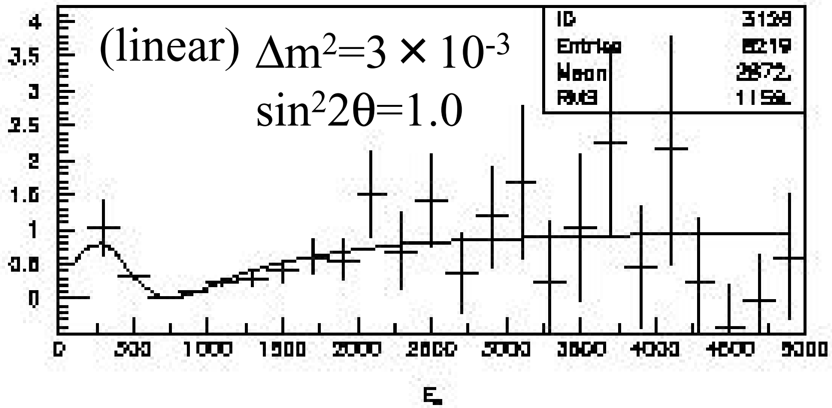
1ring FC μ-like

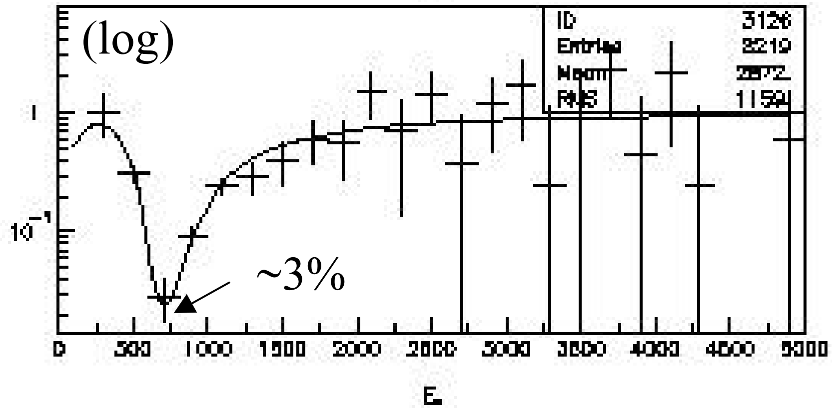




Reconstructed Eν (MeV)

Ratio after BG subtraction



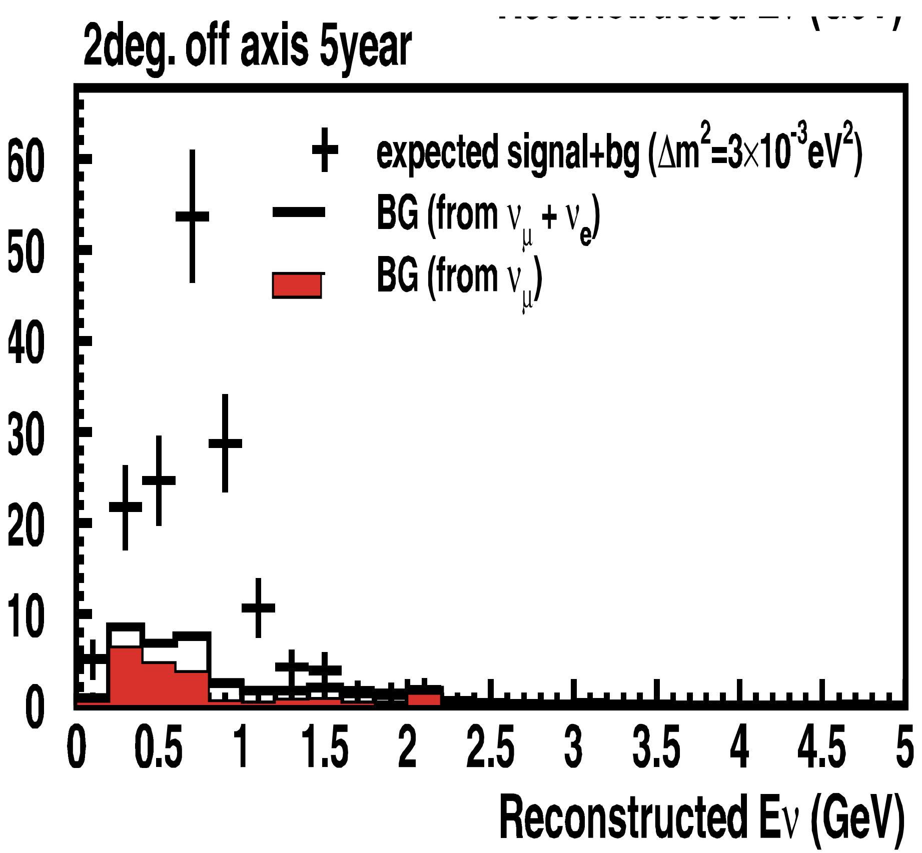


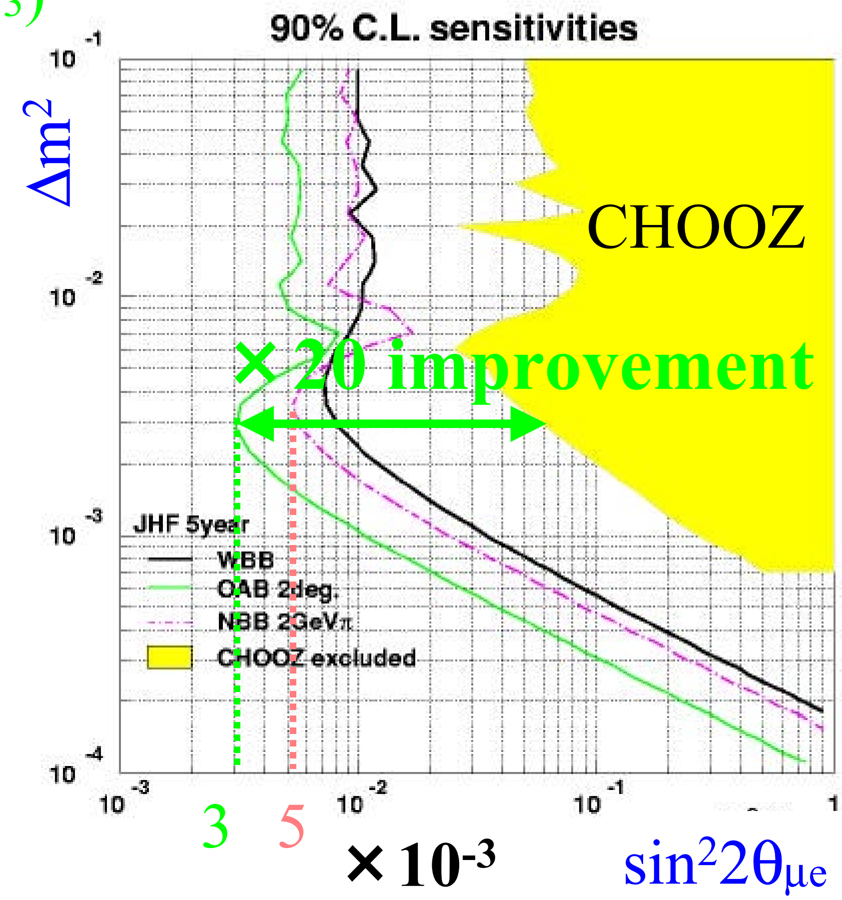
Fit with $1-\sin^2 2\theta \cdot \sin^2(1.27\Delta m^2 L/E)$

ν_e appearance

Background rejection against NC π^0 is improved.

$\sin^2 2\theta_{\mu e}=0.05$ ($\sin^2 2\theta_{\mu e} \equiv 0.5\sin^2 2\theta_{13}$)

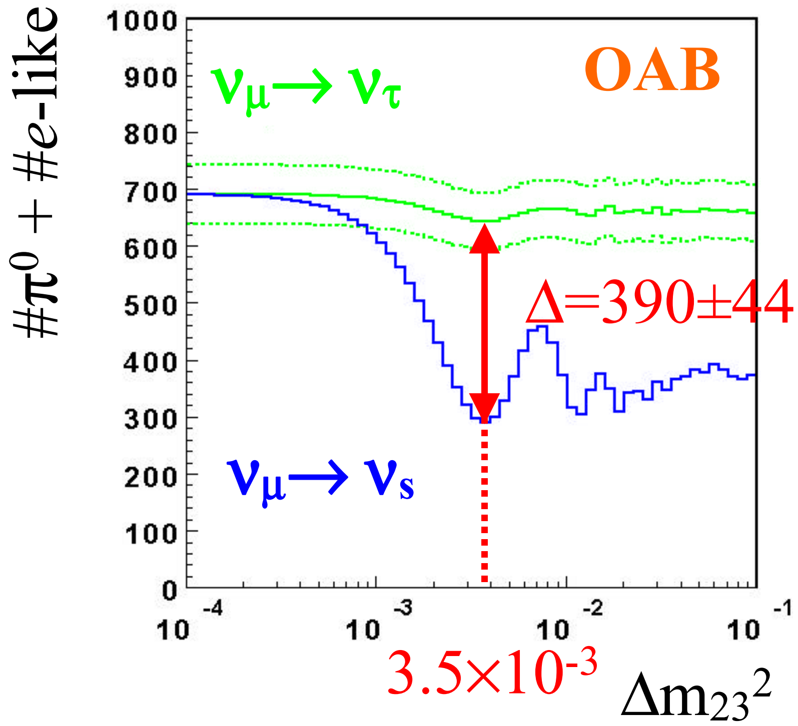




$\nu_\mu \rightarrow \nu_\tau$ confirmation

- NC π^0 interaction ($\nu + N \rightarrow \nu + N + \pi^0$)
  - $\nu_\mu \rightarrow \nu_e$ CC + NC(~0.5CC) ~0 ($\sin^2 2\theta_{\mu e}$~0)
    - ν_μ CC + NC(~0.5CC) ~0 (maximum oscillation)
    - ν_τ NC

#π^0 is sensitive to ν_τ flux. ⇨ Limit on ν_s ($\delta f(\nu s)$~0.1)



4. Physics sensitivity in Phase-II

2years for ν_μ and 6 years for $\bar{\nu}_\mu$ running

→ Search for CP violation in ν oscillation.

- standard: $\nu_\mu \to \nu_e$ vs $\nu_\mu \to \nu_e$
- non-standard: $\nu_\mu \to \nu_\tau$ vs $\nu_\mu \to \nu_\tau$ w/ NC

→ Search for $\nu_\mu \to \nu_e$

→ Search for proton decay.

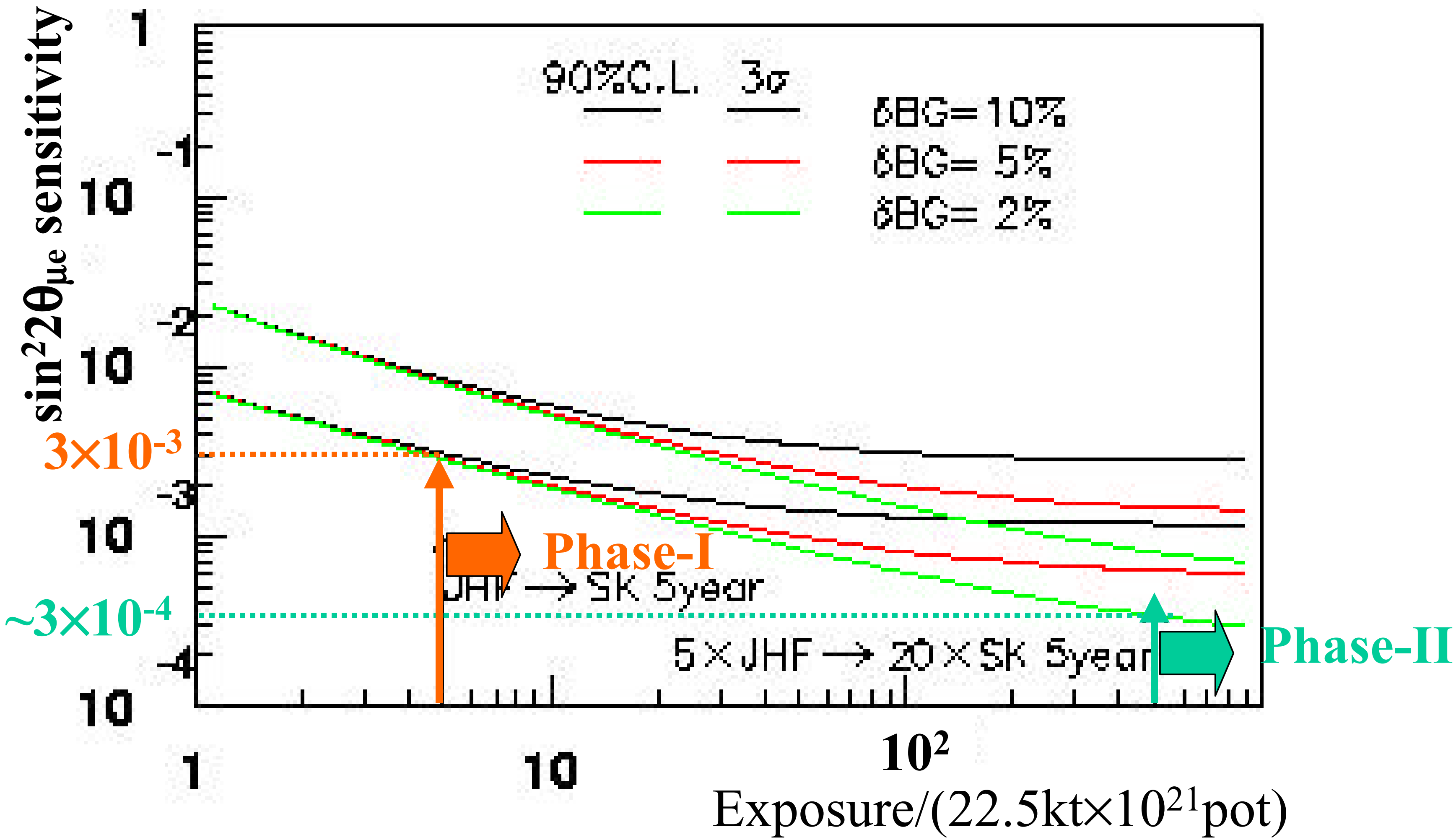
Sensitivity (goal):

$\sin^2 2\theta_{13}$ $< 1 \times 10^{-3}$ (90% CL)

$|\delta|$ $>20°$ (3σ discovery)

at ($\Delta m_{12}^2 = 5 \times 10^{-5}$ eV^2 , $\Delta m_{23}^2 = 3 \times 10^{-3}$ eV^2)

Search for $\nu_\mu \rightarrow \nu_e$



π^0 background has to be understood with 2% level.

(ν physics at a front detector)

CP Violation Study

- Compare $\nu_\mu \rightarrow \nu_e$ with $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$

N(e^+)

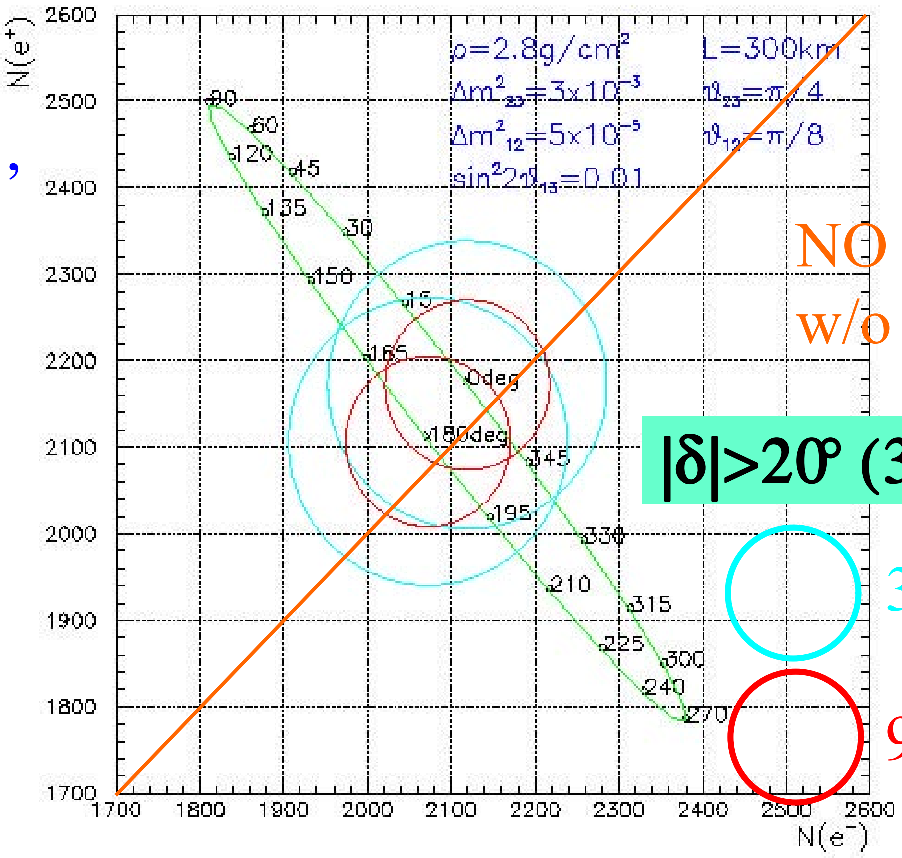
$\Delta m_{12}^2 = 5 \times 10^{-5} eV^2$,
$\Delta m_{23}^2 = 3 \times 10^{-3} eV^2$
$\sin^2 2\theta_{13} = 0.01$
$\theta_{23} = \pi/4$, $\theta_{12} = \pi/8$

Asymmetry

$$\equiv \frac{N(e^+) - N(e^-)}{N(e^+) + N(e^-)}$$

$$\approx \frac{\sim 2000 - \sim 2000}{\sim 2000 + \sim 2000}$$

$$\approx 0.02$$



NO CP violation w/o matter effect.

|δ|>20° (3σ discovery)

3σ discovery

90% C.L.

N(e^-)

5. Summary and Conclusion

- The experiment is expected to start in **2007** at the same time of the completion of JHF 50 GeV PS.
  - The experiment is not approved yet, but ………
- The features of the experiment are:
  - MW class 50 GeV proton accelerator (0.77MW $\rightarrow$ 4MW)
  - ~1GeV Narrow band neutrino beam (L=295km)
  - Gigantic Water Cherenkov detectors with/ neutrino energy reconstruction by quasi-elastic interaction. (22.5kton $\rightarrow$ 1000kton)

Physics Reach (see hep-ex/00000000, KEK-report 2001-4 soon)

- Phase-I (0.77MW + 22.5kt):

  NC interaction: Establish $\nu_\mu \rightarrow \nu_\tau$ and limit on $\nu_\mu \rightarrow \nu_s$

  $\nu_\mu \rightarrow \nu_\mu$: $\delta \sin^2 2\theta_{23} < 0.01$

  $\nu_\mu \rightarrow \nu_e$: $\sin^2 2\theta_{13} < 6 \times 10^{-3}$ (90% CL)

  $\nu_\mu \rightarrow \nu_\mu$: $\delta \Delta m_{23}^2 < 1 \times 10^{-4} \mathrm{eV}^2$

  at ($\sin^2 2\theta = 1.0$, $\Delta m^2 = 3.2 \times 10^{-3} \mathrm{eV}^2$)

- Phase-II (4MW + 1000kt):

  $\nu_\mu \rightarrow \nu_e$: $\sin^2 2\theta_{13} < 1 \times 10^{-3}$ (90% CL)

  $\nu_\mu \rightarrow \nu_e$ vs $\nu_\mu \rightarrow \nu_e$: $|\delta| > 20°$ (3σ discovery)

  at ($\Delta m_{12}^2 = 5 \times 10^{-5} \mathrm{eV}^2$, $\Delta m_{23}^2 = 3 \times 10^{-3} \mathrm{eV}^2$)