Dec 10, 2001
@NP01

The JHF-Kamioka Neutrino experiment

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for JHF-SK working group

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

JHF is an tentative name, and will be renamed soon.

JHF-SK Neutrino Working Group

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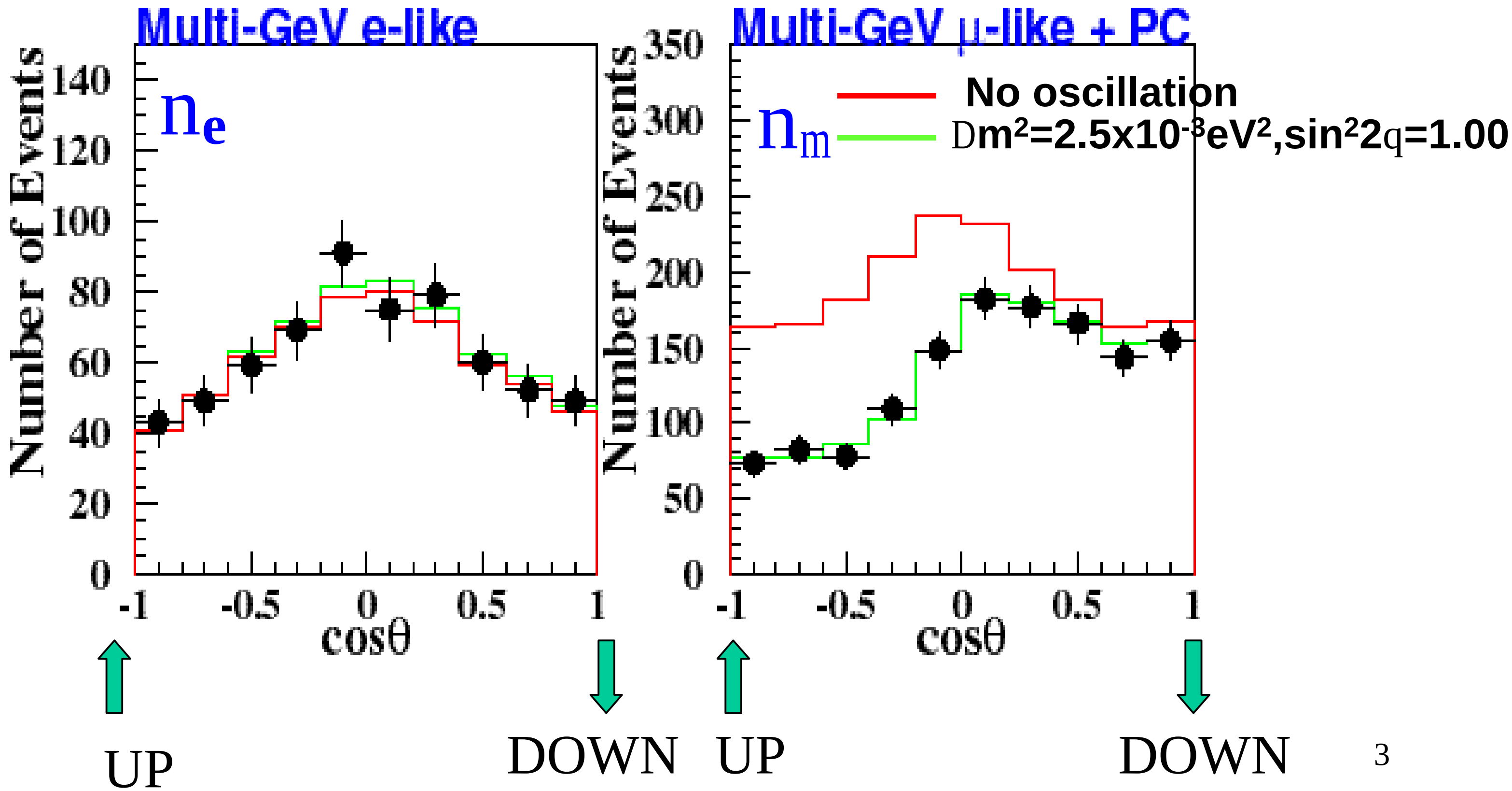
In addition to the above user group, the neutrino facility construction group is OFFICIALLY formed at KEK.

15,5

1. Introduction

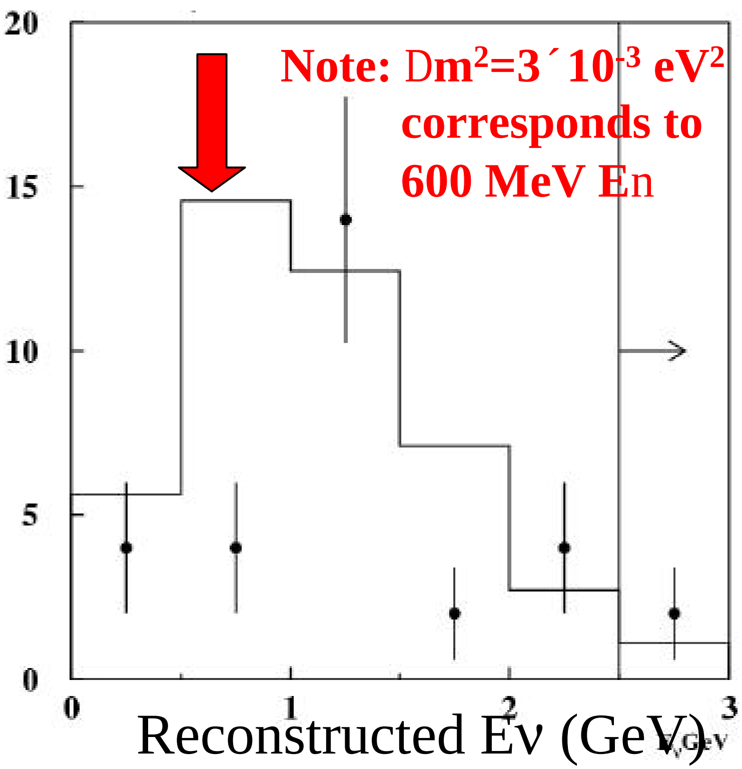
- Super-Kamiokande discover **neutrino oscillation** in atmospheric neutrinos in 1998.

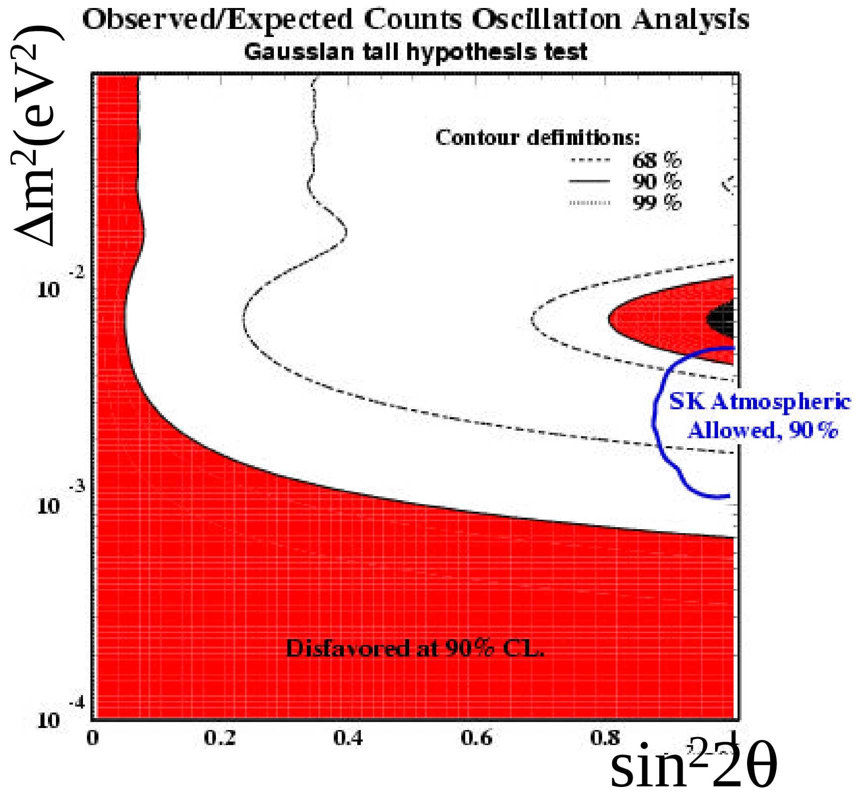
$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta \, \sin^2(1.27\, \Delta m^2\, L/E)$$



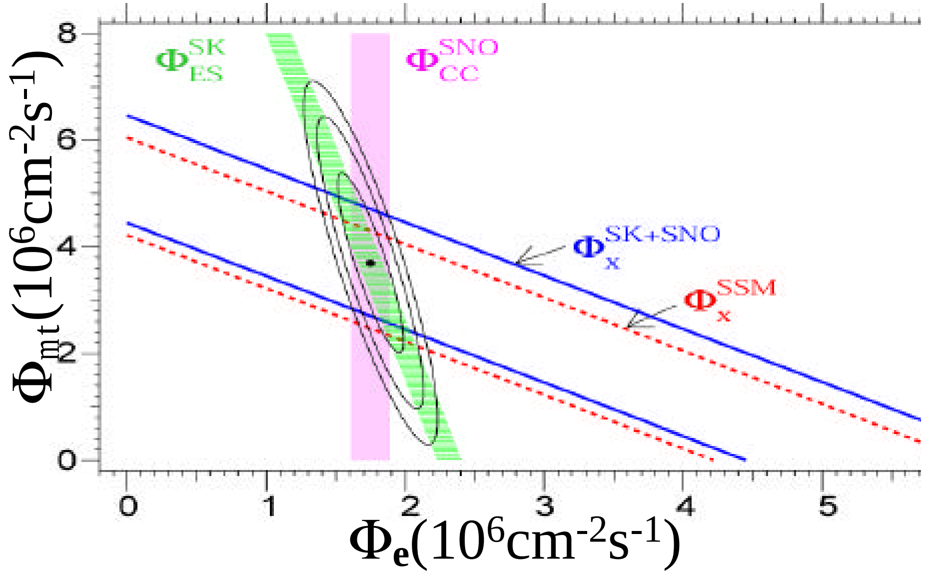
NEW K2K will confirm the neutrino oscillation soon.

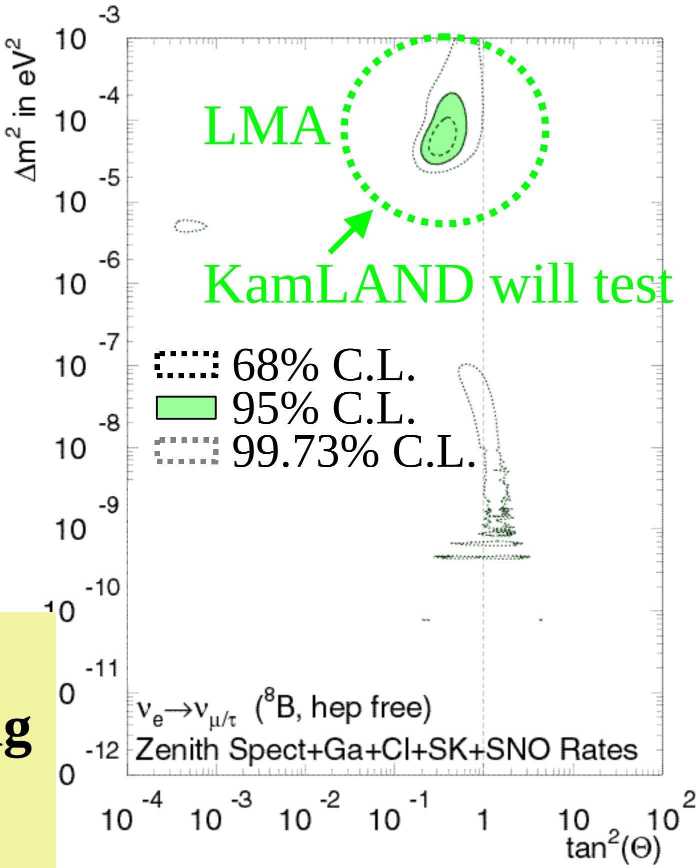
- 56 Events are observed to an expectation of $80^{+6.1}_{-6.6}$ events with ~1/2 protons on target of the proposal .
  - The probability of null oscillation is less than 3%.





Super-K and SNO establish neutrino oscillation in solar neutrinos in 2001





SMA, LOW and VAC solutions are disfavored at 95% C.L. by combining rates and SK zenith spectra
LMA reproduces all the data well

Lepton Sector Mixing

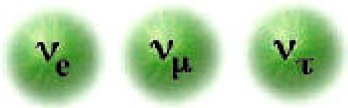
- If neutrinos are massive particles, then it is possible that the **mass eigenstates** and the **weak eigenstates** are not the same:

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

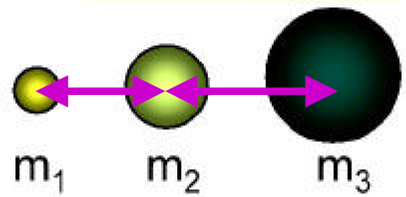
Weak eigenstates
„flavor eigenstates"

3 independent parameters + 1 complex phase

Mass eigenstates



q_{12}, q_{23}, q_{13}
$+ d$



$Dm^2{}_{12}, Dm^2{}_{23}$

MNS (Maki-Nakagawa-Sakata) matrix

Underlying Questions

- Why is the neutrino mass so light?
- Is the framework of Lepton Sector Mixing right?
- Why are the quark sector mixing and the lepton sector mixing so different?

quark

M3>>M2>>M1
small mixing

neutrino

M3~M2>~M1
large mixing

What is there behind of the yukawa coupling of Higgs particle?

GUT?

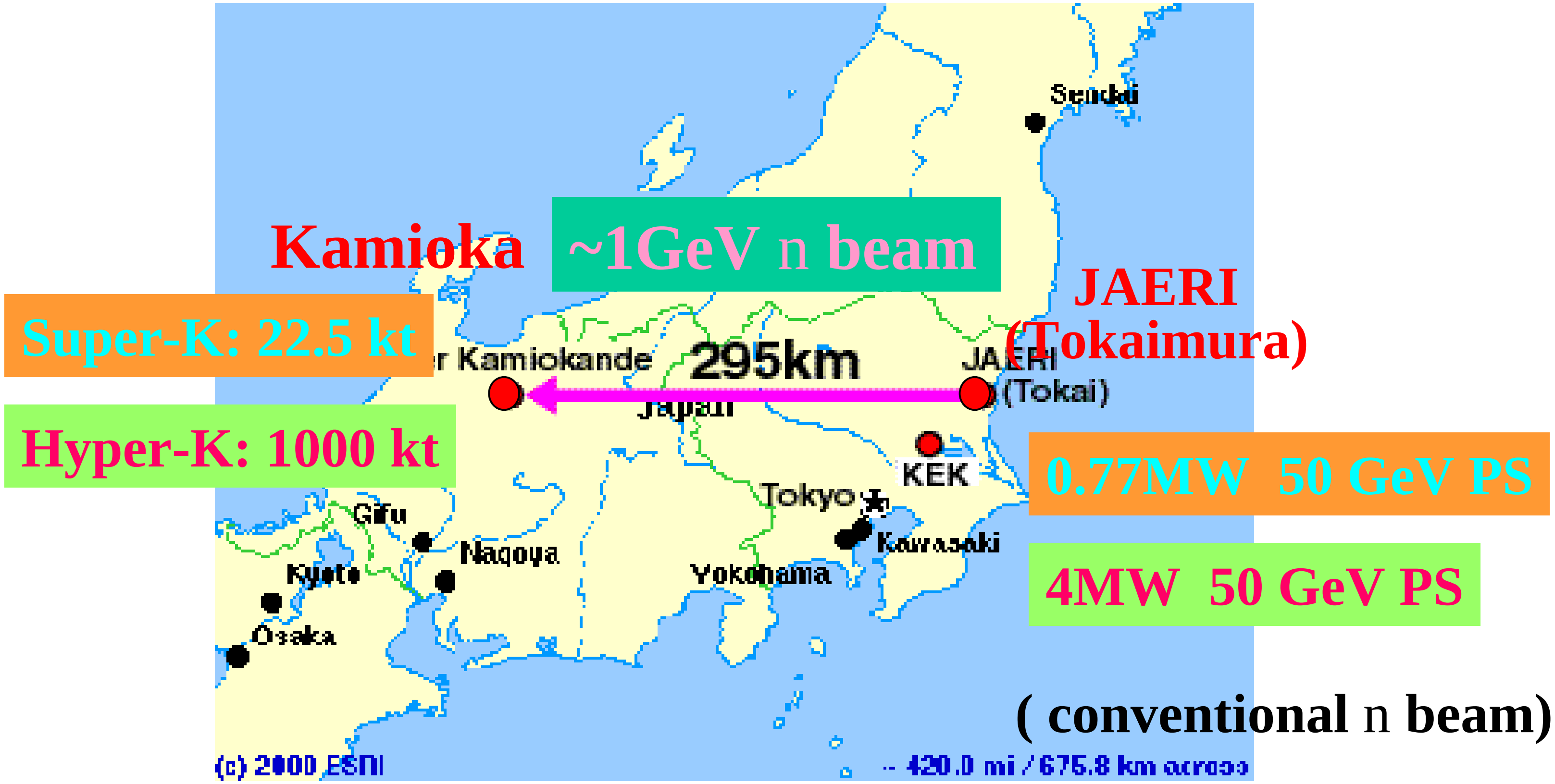
Anarchy? (see Murayama-san's talk at KEK topical conference)

Anything other?

What should we do next as an accelerator n physics?

- Confirmation of $\nu_m \rightarrow \nu_t$
  - MINOS, OPERA, ICARUS, JHF-SK
- Discovery of $\nu_m \rightarrow \nu_{\mathbf{e}}$ at $\Delta m^2_{atm.}$
  - MINOS, JHF-SK
- Precise measurement of neutrino oscillation. (observation of oscillation peak)
  - MINOS, JHF-SK
- CP violation in neutrino oscillation.
  - JHF-SK2, ν-factory.
- Confirm or Reject LSND anomaly.
  - JHF-SK w/ a detector at 2km.

2.Overview of the experiment



Phase-I (0.77MW + Super-K)

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

<u>n **oscillation**</u>

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

$$P(n_m \to n_e) = \sin^2 2q_{13} \bullet \sin^2 q_{13} \bullet \sin^2\left(\frac{1.27\Delta m_{23}^{\ 2}\left[eV^2\right] \bullet L[km]}{E[GeV]}\right)$$

at θ_{23}~$\pi/4$ and θ_{13}~0

$$P(n_m \to n_m) = 1 - \sin^2 2q_{mt} \bullet \sin^2\left(\frac{1.27\Delta m_{23}^{\ 2}\left[eV^2\right] \bullet L[km]}{E[GeV]}\right) - P(n_m \to n_e)$$

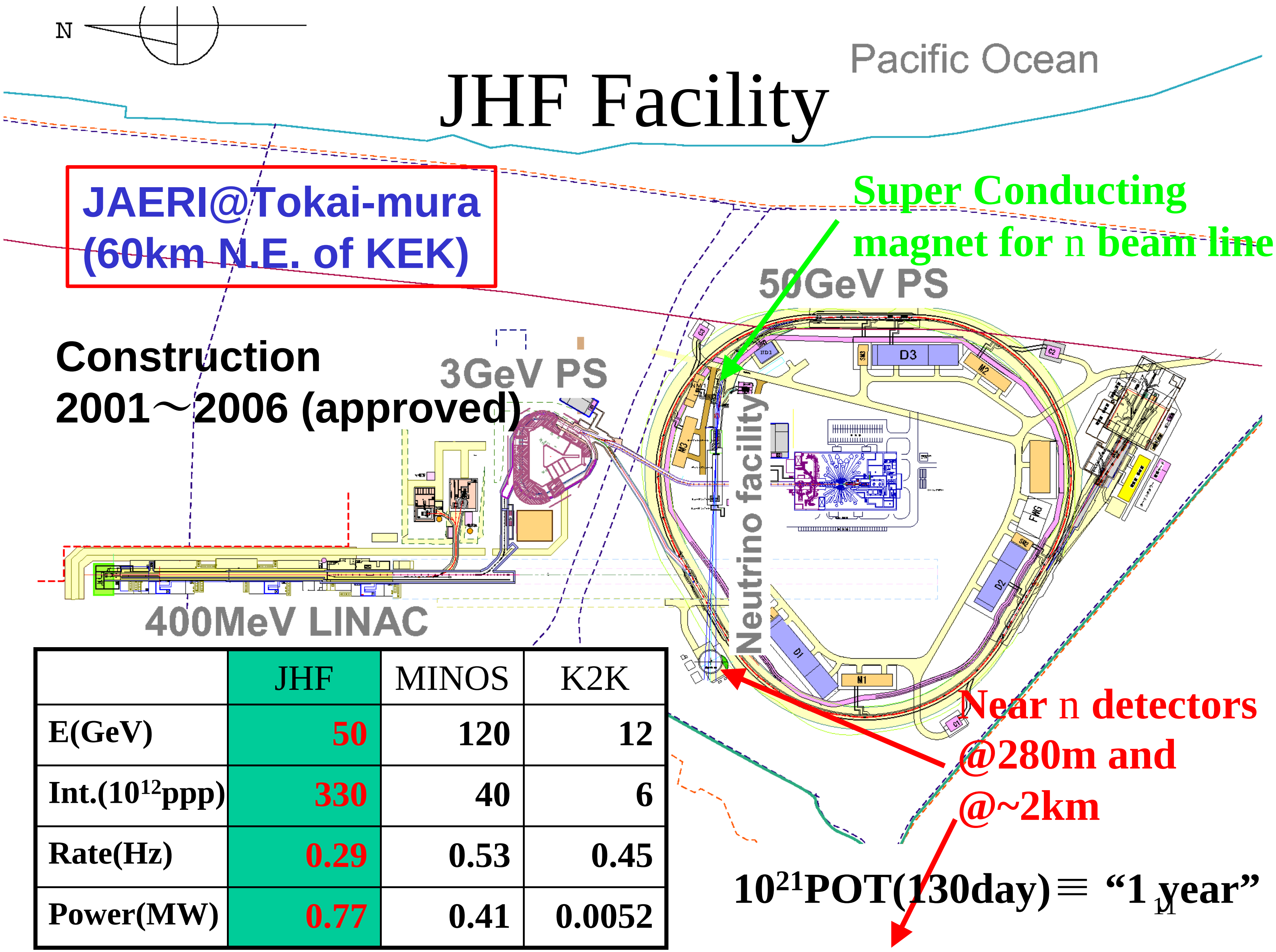
$$P(n_m \to n_e) = \sin^2 2q_{em} \bullet \sin^2\left(\frac{1.27\Delta m_{23}^{\ 2}\left[eV^2\right] \bullet L[km]}{E[GeV]}\right)$$

$$\sin^2 2q_{mt} \approx \sin^2 2q_{23}, \sin^2 2q_{em} \approx \frac{1}{2}\sin^2 2q_{13} \approx 2\left|U_{e3}\right|^2$$

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”

n beam at JHF

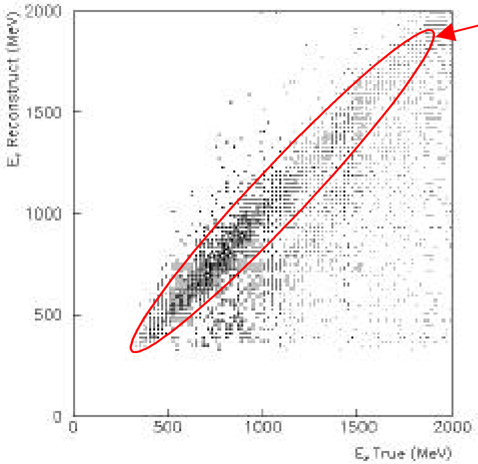
- **Principle**
  - **Intense Narrow Band Beam**
  - Beam energy is tuned to be at the oscillation maximum.
    - High sensitivity
    - Less background

Δm^2=1.6~4x10^{-3}eV^2

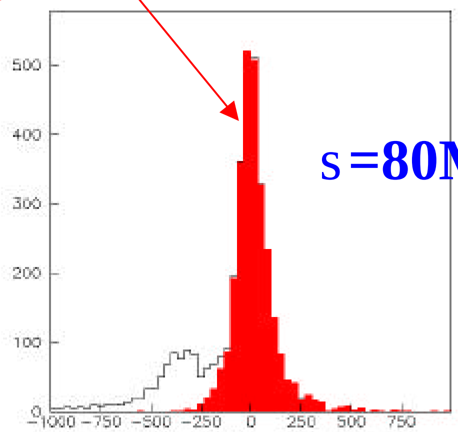
E_n=0.4~1.0GeV

  - ~1 GeV beam energy for **Quasi-elastic** interaction.

Ev(reconstruct)



Ev (True)

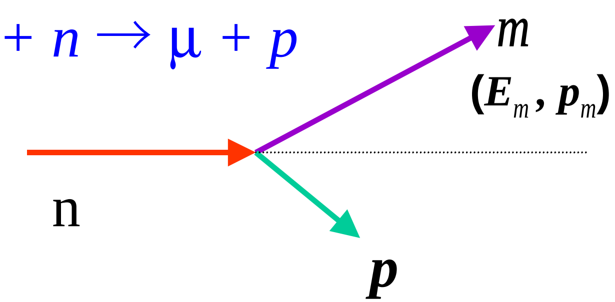


s =80MeV

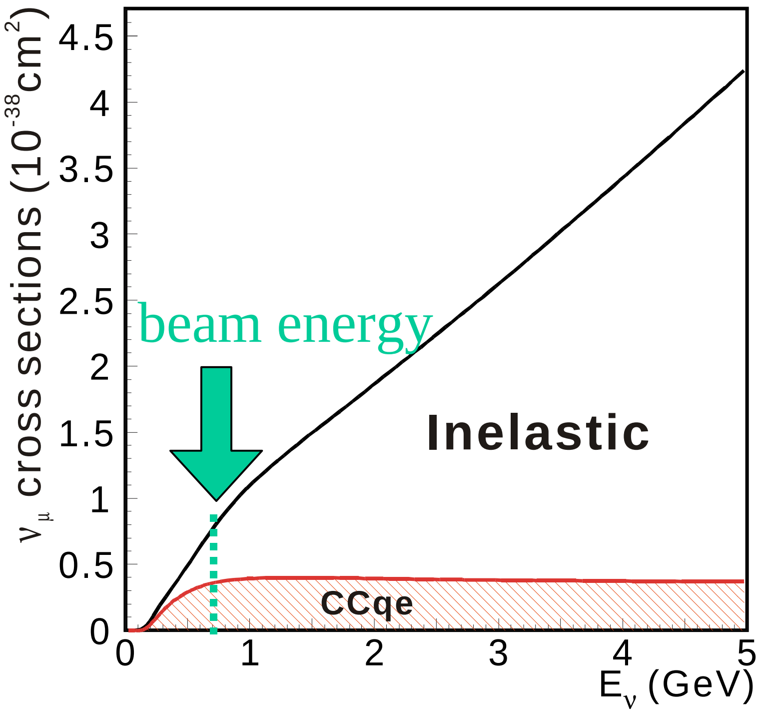
Ev(reconstruct) – Ev (True) (MeV)

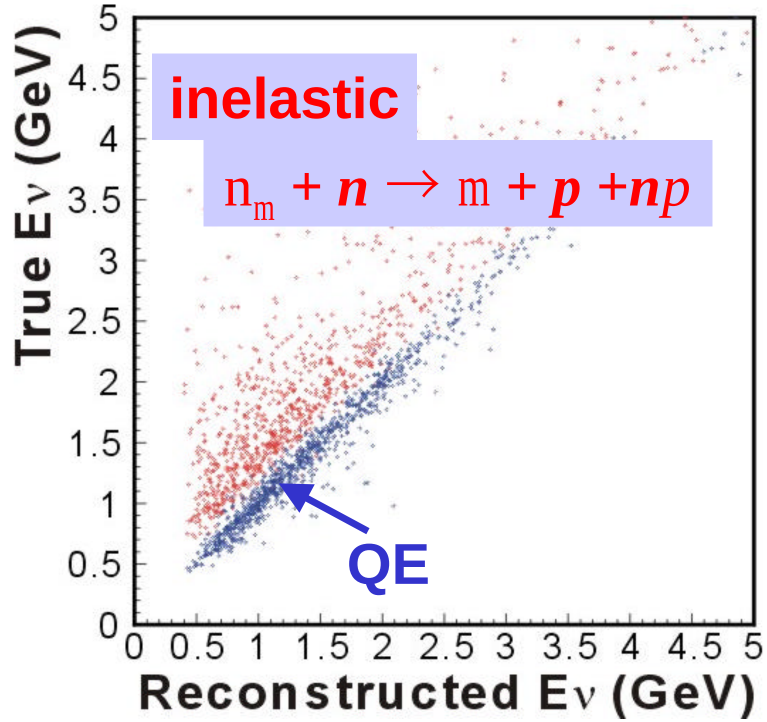
Assume CC Quasi Elastic (QE) reaction

$\nu_\mu + n \rightarrow \mu + p$



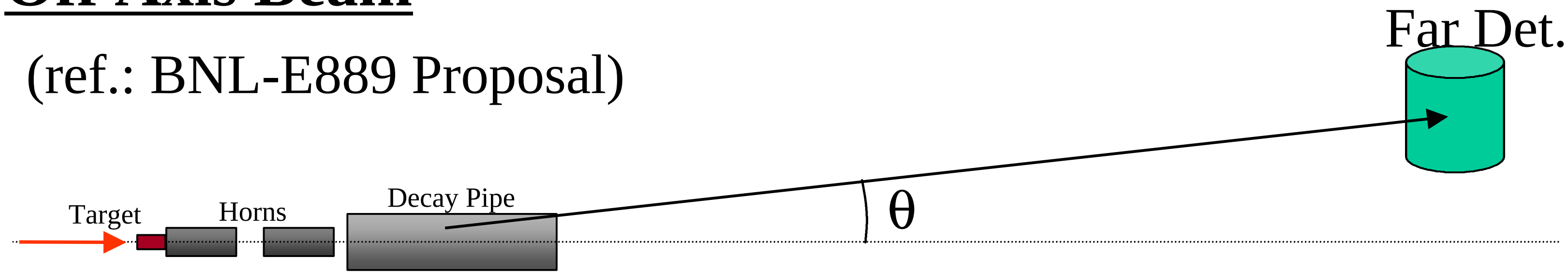
$$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$





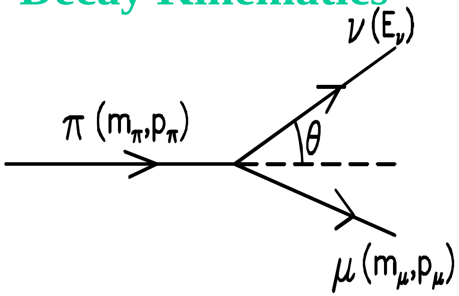
Off Axis Beam

(ref.: BNL-E889 Proposal)

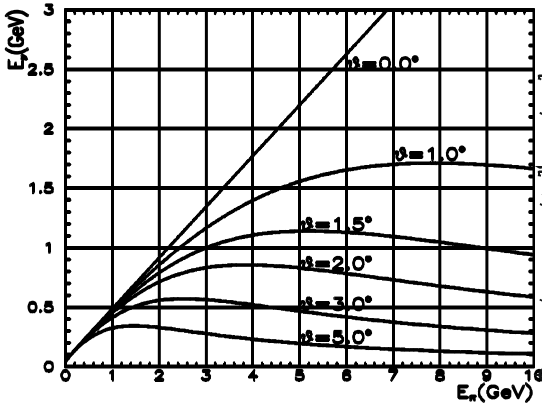


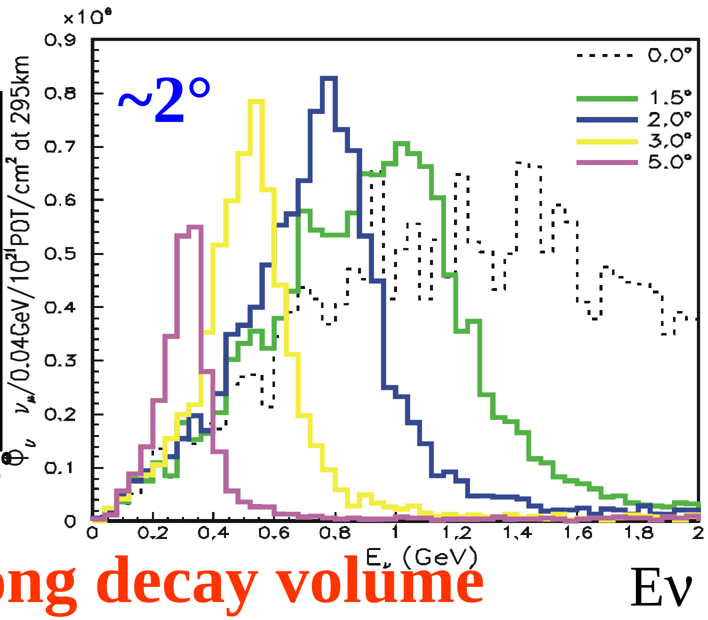
WBB w/ intentionally misaligned beam line from det. axis

Decay Kinematics



$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\theta)}$$



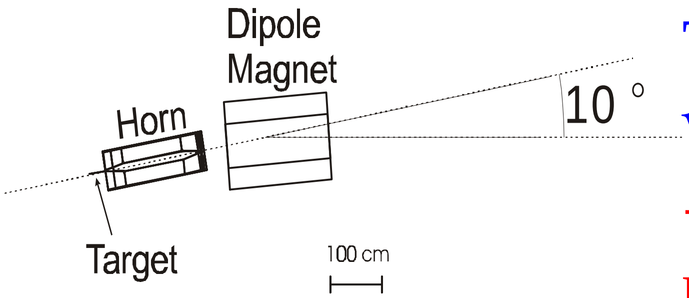


~3100 int./22.5kt/yr w/ 80m long decay volume

n_e: 1.0% (0.2% @ peak)

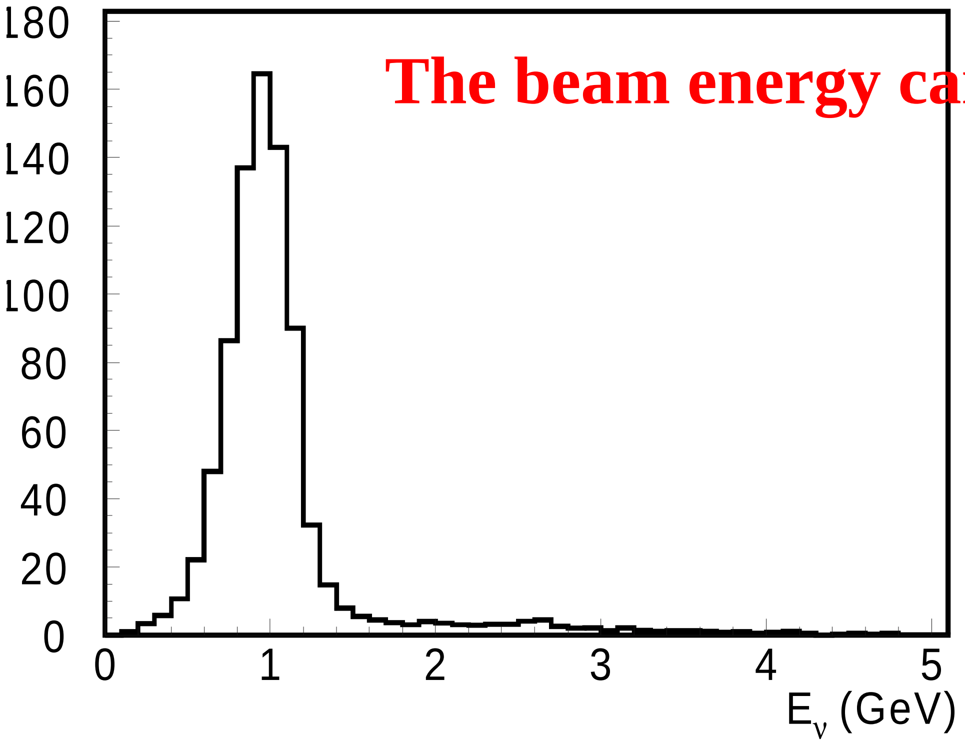
(Present design; 130m → 40% more ν)

Narrow Band Beam only to a Front detector



The beam will be used to study
ν interactions at the front detectors.
→This is also essential to reduce sys. uncertainty for CP measurement.

The beam energy can be easily tuned.



n detectors at JHF

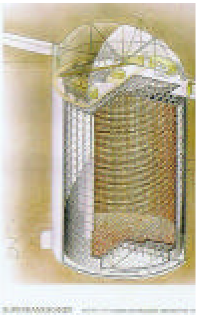
Far detector: A Water Cherenkov detector (SK exists)

- generally easy to build a larger detector
- less NC π^0 background to $\nu_\mu \rightarrow \nu_e$
- good ν energy reconstruction with QE interaction.
- good particle ID capability.

Schematic drawing of Super-Kamiokande and Hyper-Kamiokande

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

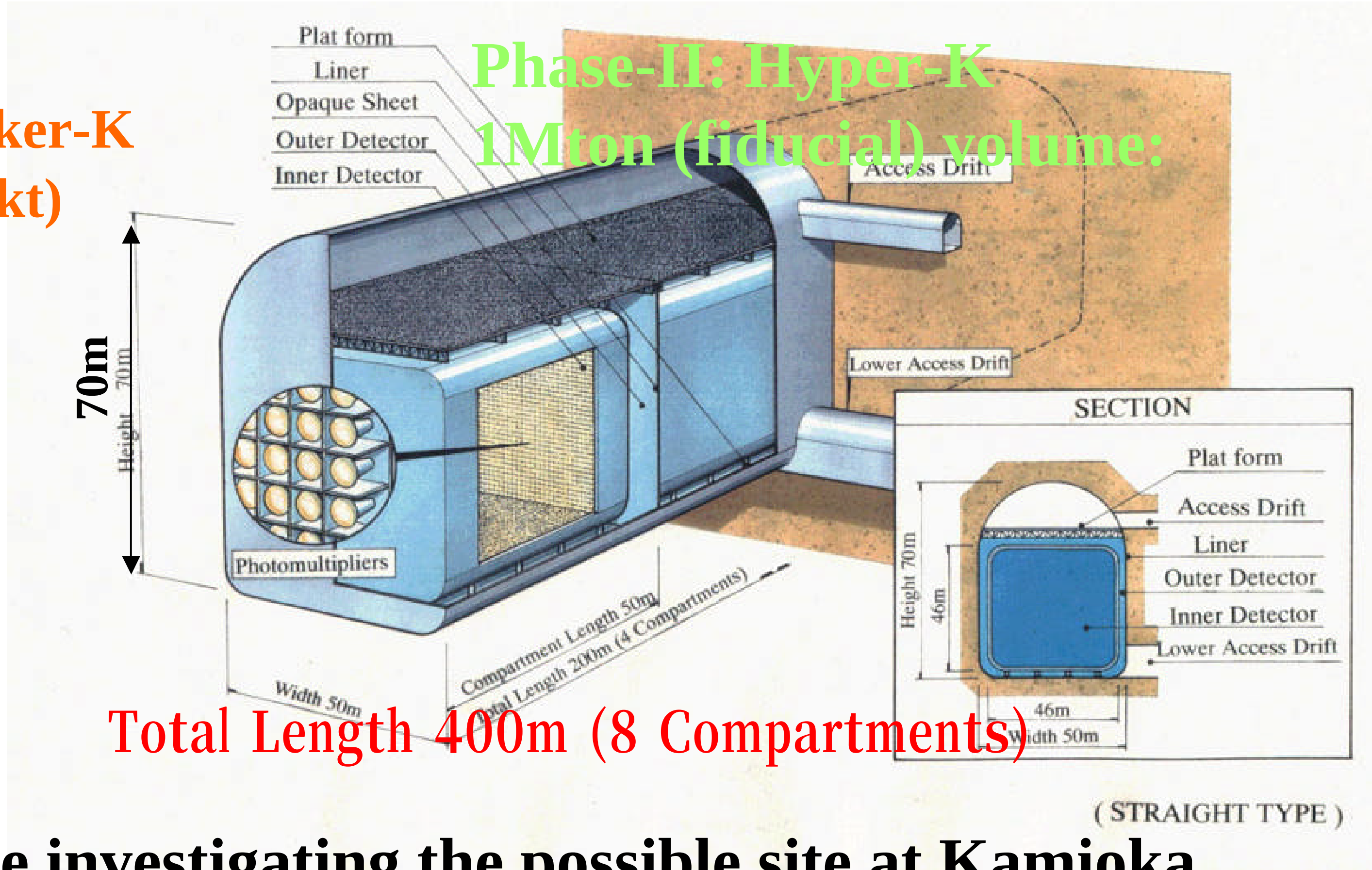
Super-K



40m

Phase-II: Hyper-K
1Mton (fiducial) volume:

70m



Total Length 400m (8 Compartments)

We are investigating the possible site at Kamioka.

Near Detectors

(Detectors at two locations are essential.)

@280m (1~10 events/spill/100ton)

Fine Grained w/ magnet.

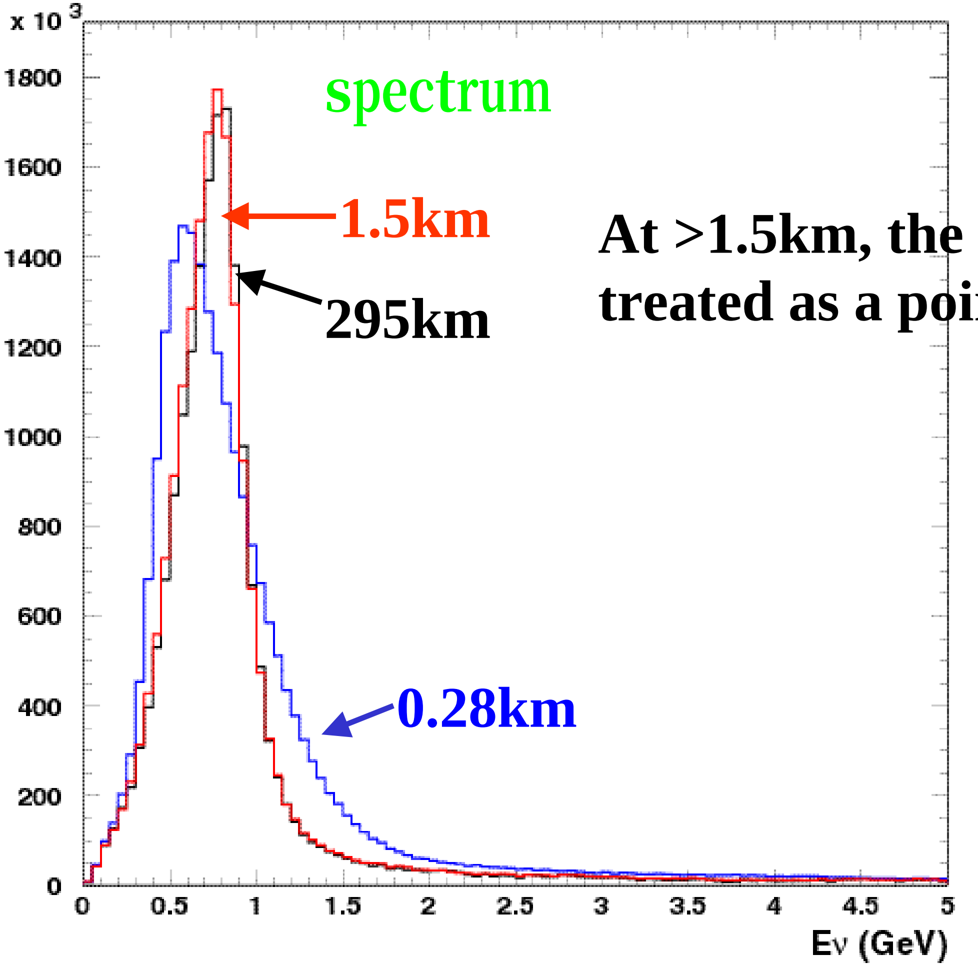
- Measure ν direction and spectrum.
- Measure wrong sign component (see CP section).
- Will be used for ν interaction study with NBB.
- Non-oscillation ν physics.

@~2km (0.1 events/spill/100ton)

Water Cherenkov + Fine Grained

- Measure ν spectrum and νe background since they are same as those at Kamioka.
- Test LSND anomaly if Mini-Boone failed to test it or discovered the new physics.

Far/Near Spectrum Ratio



At >1.5km, the n **source is treated as a point source**

3. Physics sensitivity in Phase-I (w/ Super-K)

5years (5´10^{21}POT) running

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

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

Sensitivity (goal):

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

$\sin^2 2\theta_{13} < 0.006$ (90% CL)

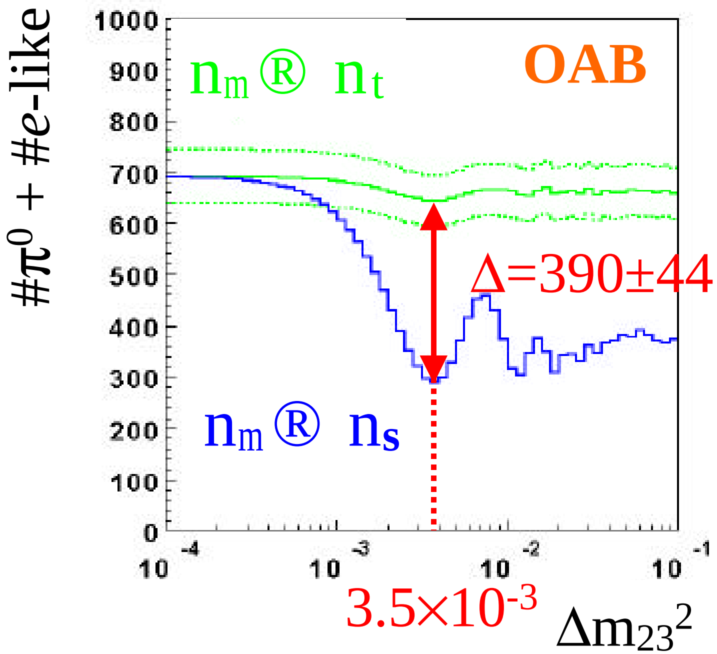
$\delta \Delta m_{23}^2 < 1 \times 10^{-4} \mathrm{eV}^2$

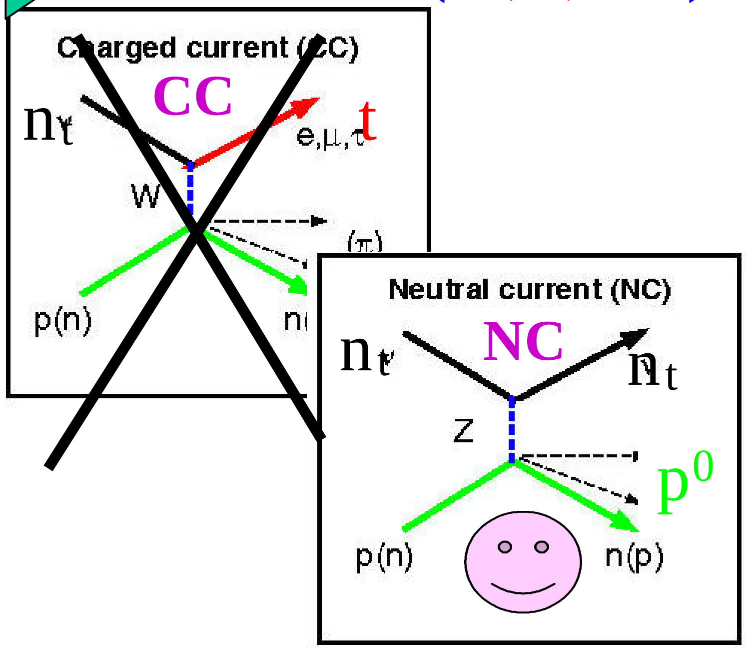
at ($\sin^2 2\theta = 1.0$, $\Delta m^2 = 3.2 \times 10^{-3} \mathrm{eV}^2$)

<u>nm →nt confirmation w/ NC interaction</u>

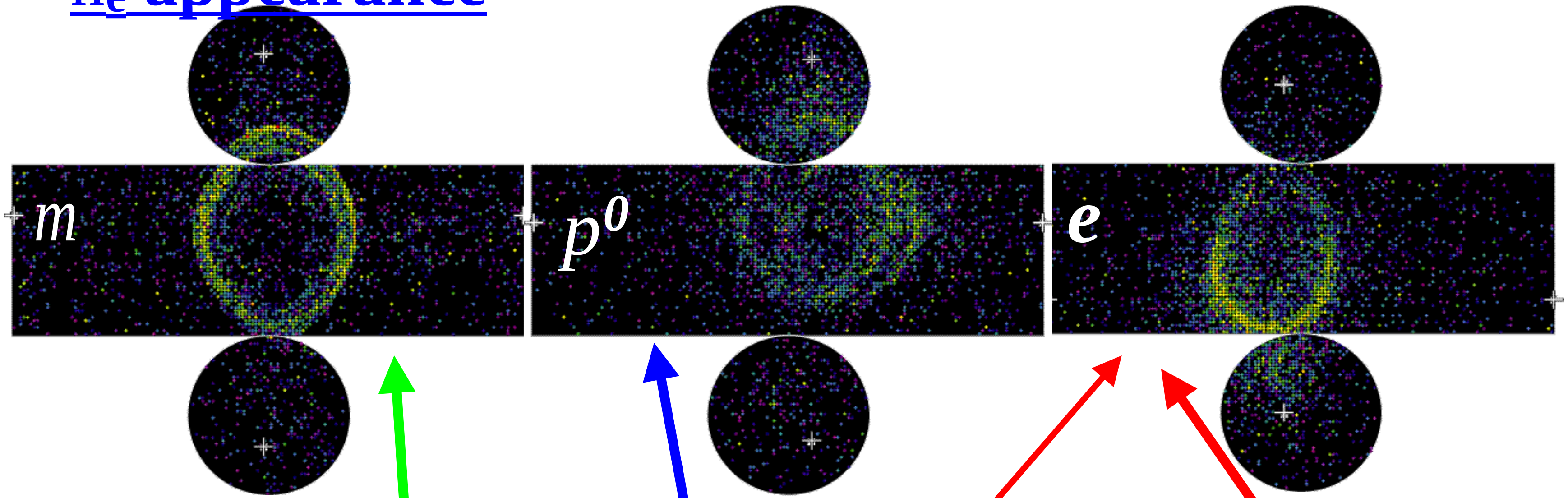
- NC π^0 interaction (ν + N → ν + N + p^0)
  - nm® ne CC + NC(~0.5CC) ~0 ($\sin^2 2\theta_{\mu e}$~0)
    - nm CC + NC(~0.5CC) ~0 (maximum oscillation)
    - nt NC

#p^0 is sensitive to nt flux. → **Limit on ns (df(ns)~0.1)**





n_e appearance

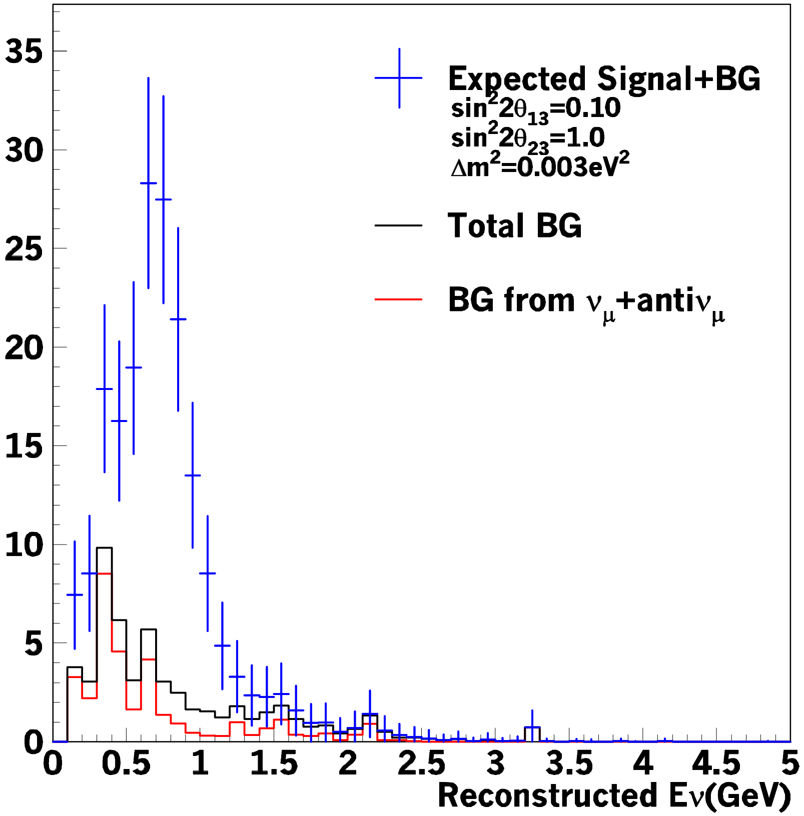


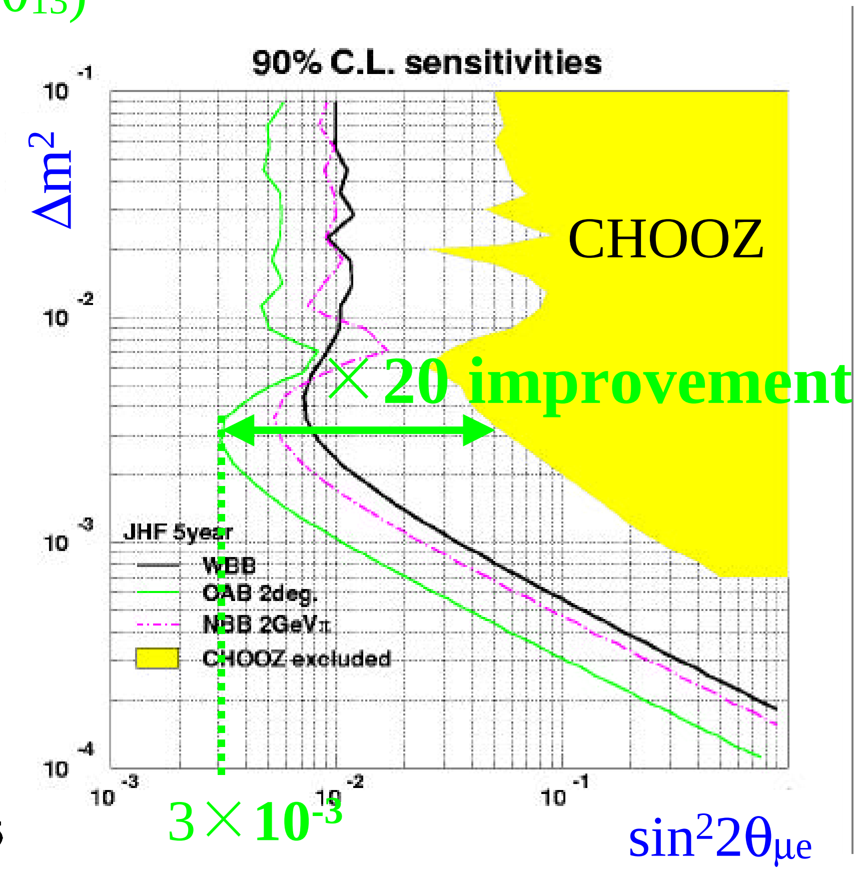
	νμC.C.	νμN.C.	Beam νe	Osc'd νe
Generated	10713.6	4080.3	292.1	301.6
1ring e-like	14.3	247.1	68.4	203.7
red. eff.	0.1%	6.1%	23.4%	67.5%
e/π^0 sep.	3.5	23.0	21.9	152.2
red.eff.	0.03%	0.6%	7.5%	50.4%
.4<Eν<1.2	1.8	9.3	11.1	123.2
red.eff.	0.02%	0.2%	3.8%	40.8%

n_e appearance

Background rejection against NC π^0 is improved.

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



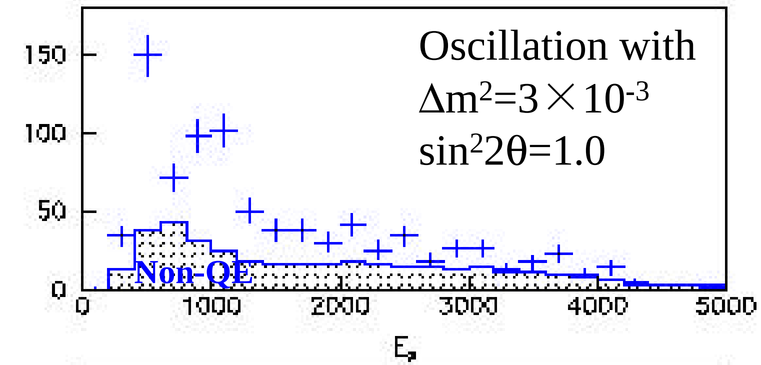


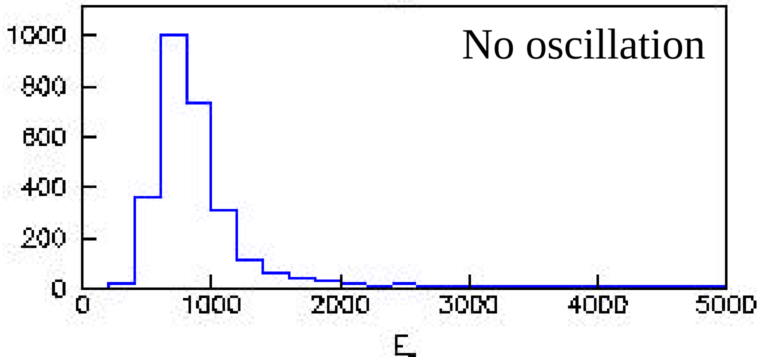
n_{μ} disappearance

Ratio after BG subtraction

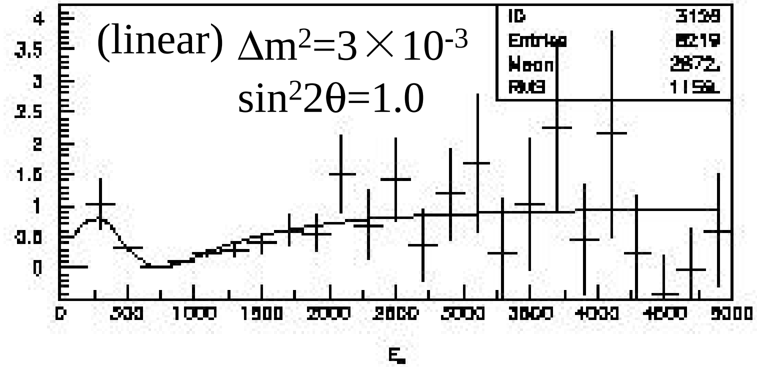
Fit with 1-$\sin^2 2q \cdot \sin^2(1.27 Dm^2 L/E)$

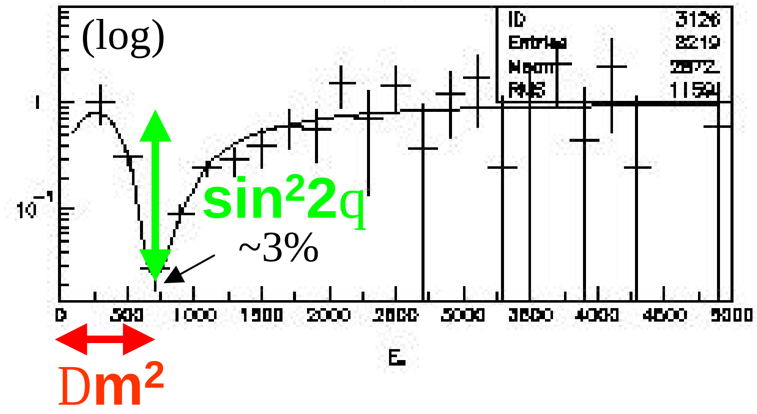
1ring FC m-like





Reconstructed En (MeV)





$d\sin^2 2q_{23} \sim 0.01$

$dDm_{23}^2 < 1 \times 10^{-4} eV^2$

4. Physics sensitivity in Phase-II

2 years (10´10^{21}POT) for n_m and
6 years (30´10^{21}POT) for $\overline{n}_m$ running

→ Search for CP violation in ν oscillation.

- standard: $\nu_\mu \rightarrow \nu_e$ vs $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$
- non-standard: $\nu_\mu \rightarrow \nu_\tau$ vs $\overline{\nu}_\mu \rightarrow \overline{\nu}_\tau$ w/ NC

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

→ Search for proton decays.

Sensitivity (goal):

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

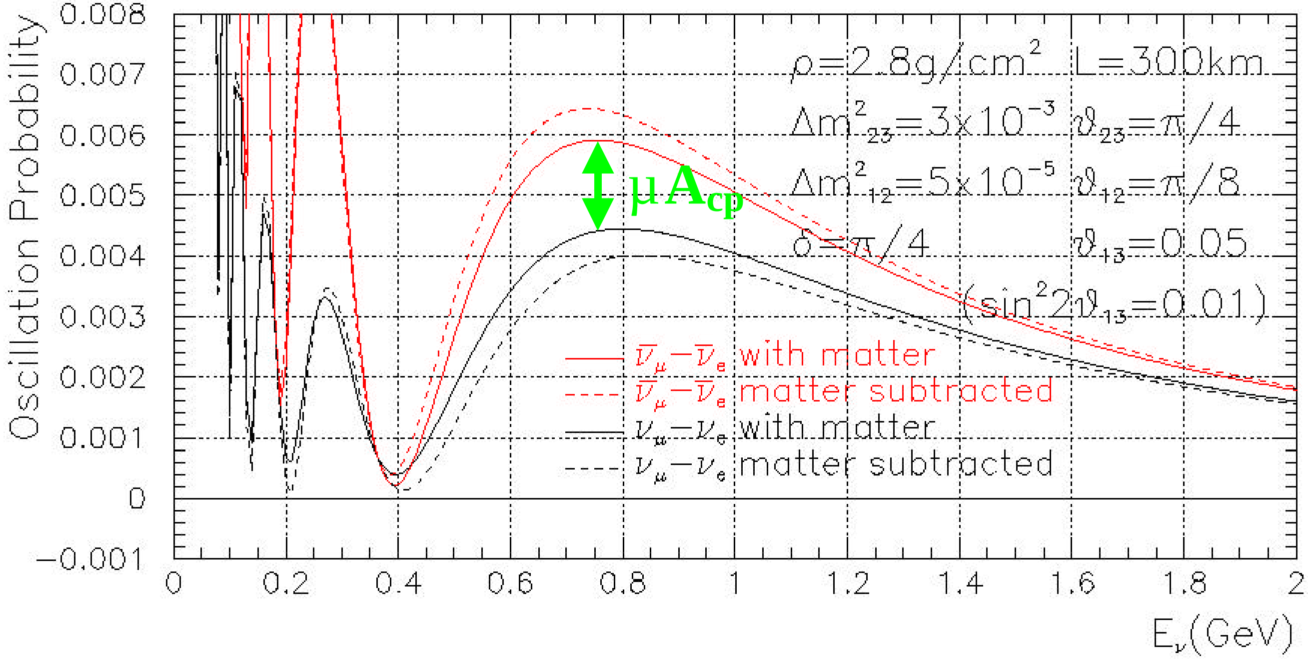
$|\delta| > 20°$ (3σ discovery)

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

$\tau_{proton} \cdot B(p \rightarrow e\pi^0, \nu K) > 10^{35}$ years

CP violation in n oscillation

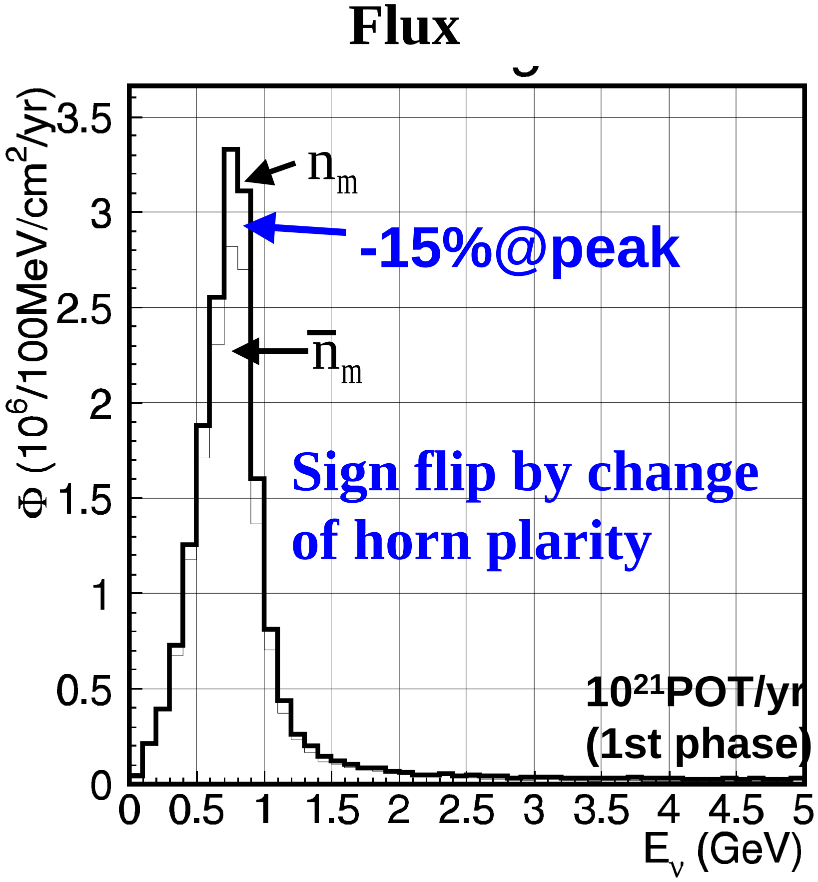
$$A_{CP} = \frac{P(n_m \to n_e) - P(\bar{n}_m \to \bar{n}_e)}{P(n_m \to n_e) + P(\bar{n}_m \to \bar{n}_e)} \approx \frac{\Delta m_{12}{}^2 L}{4E_n} \bullet \frac{\sin 2q_{12}}{\sin q_{13}} \bullet \sin d$$

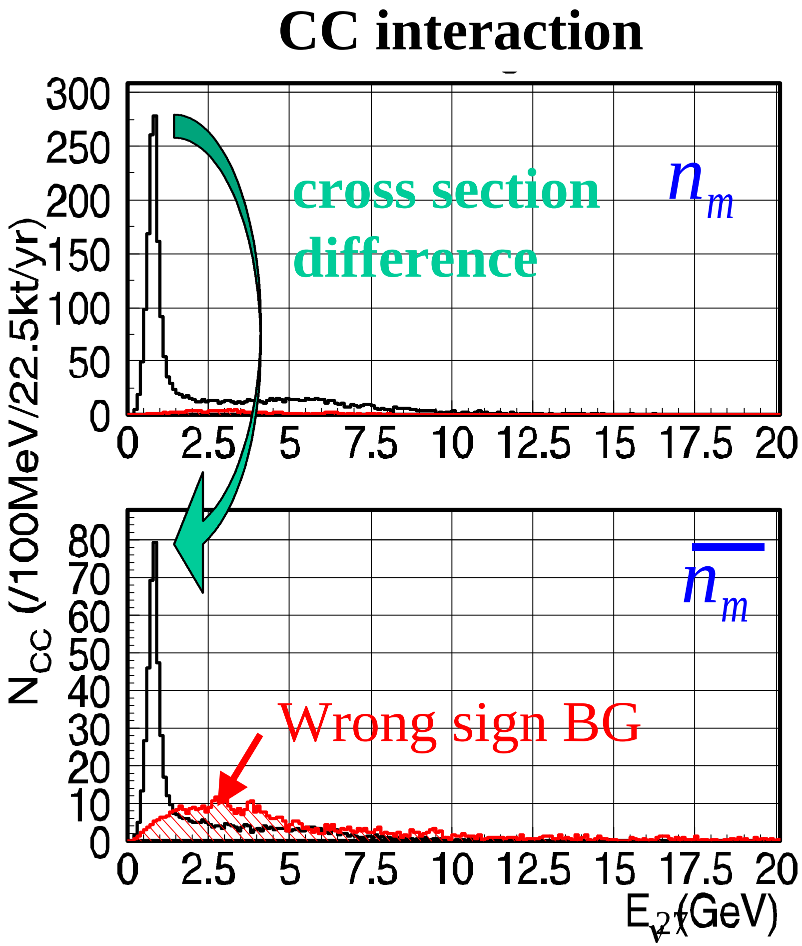


L=295km : small matter effect

Eν~1 GeV : large CP asymmetry

$n_m/\overline{n}_m$ flux for CP violation search.





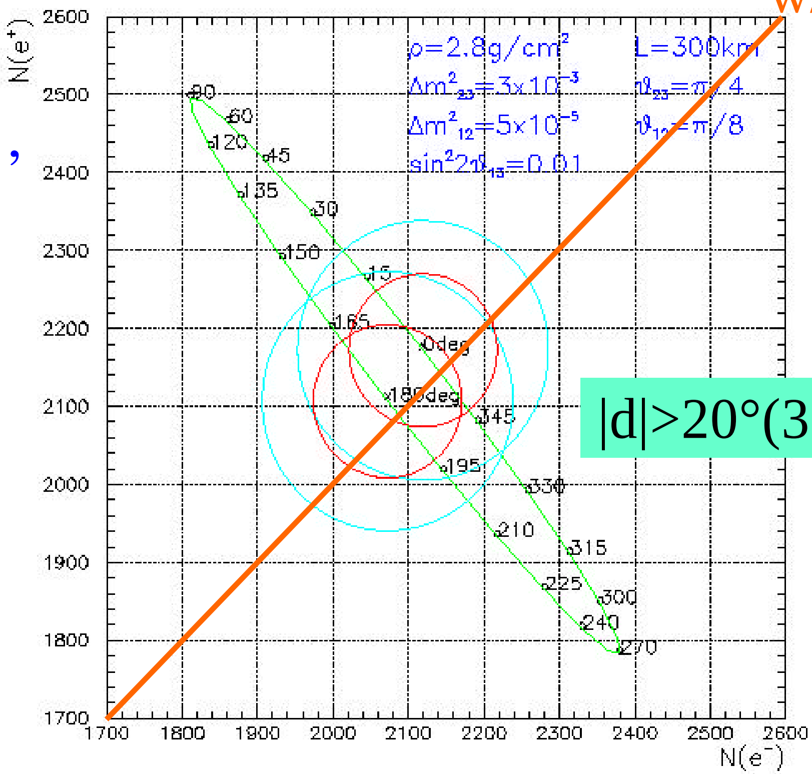
CP Violation Study

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

NO CP violation
w/o matter effect.

N(e⁺)

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



|d|>20°(3s **discovery**)

N(e⁻)

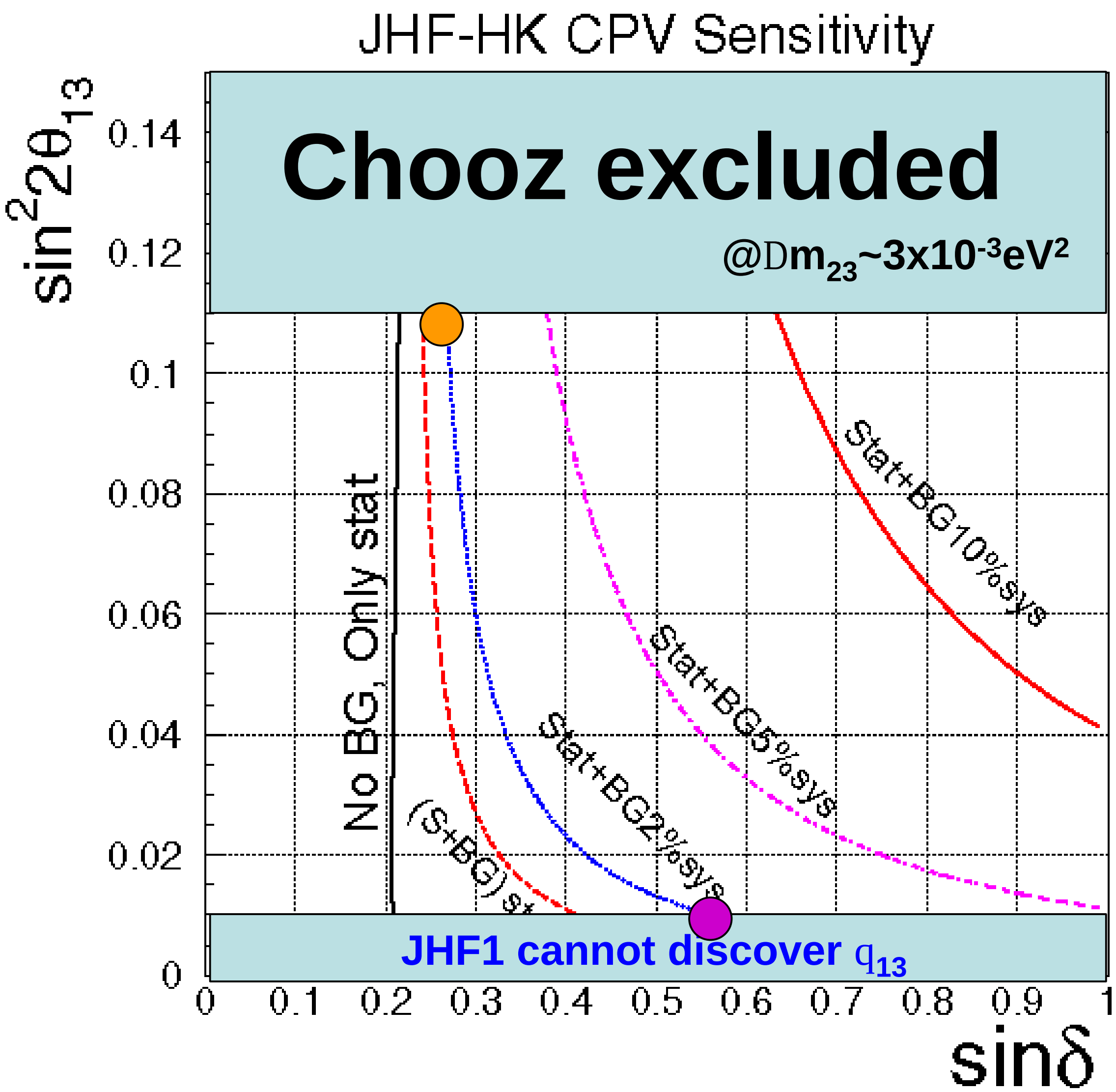
Asymmetry

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

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

$$\approx 0.02$$

CP Sensitivity(3 s)

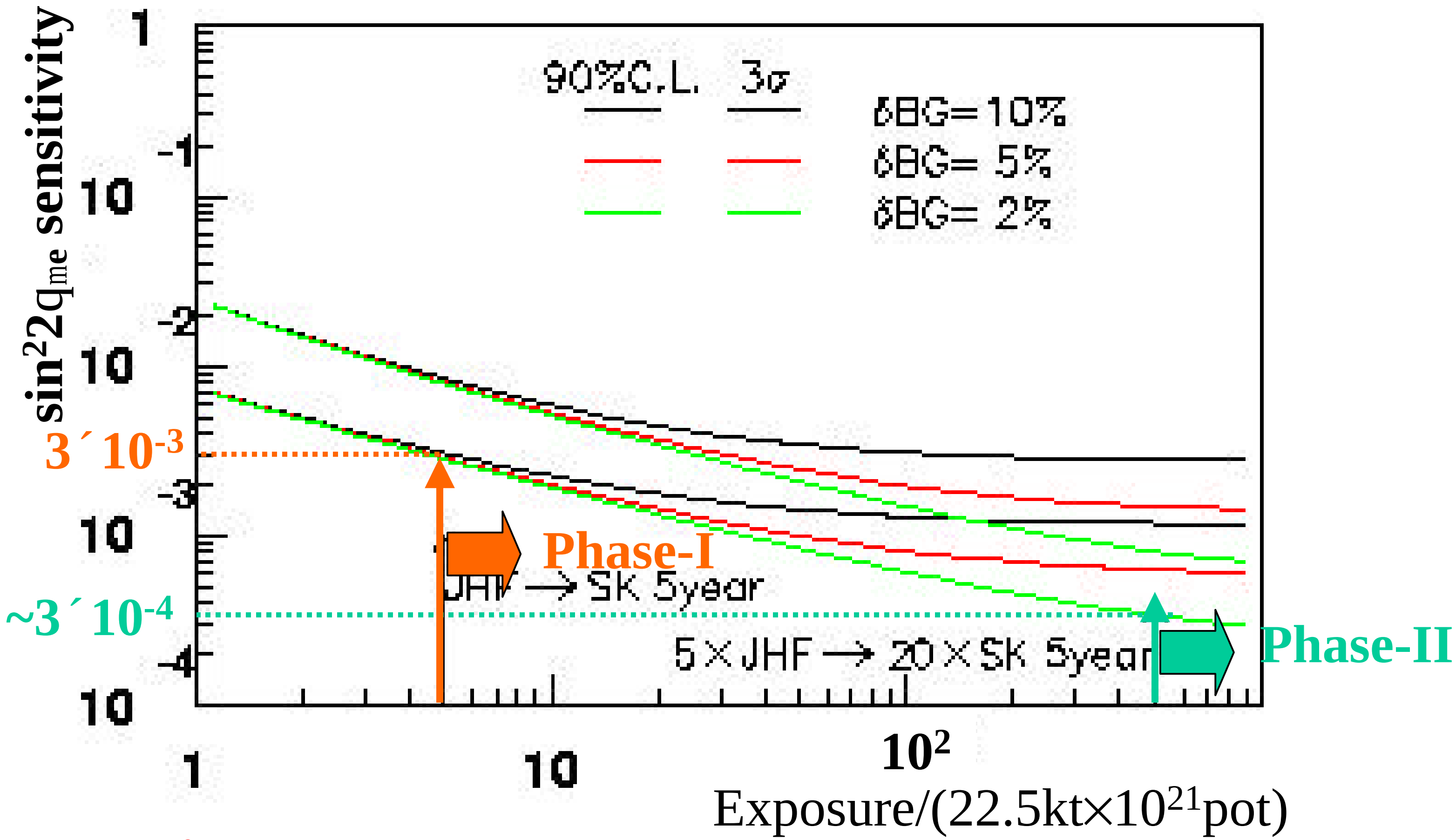


assuming 2% BG uncertainty

sin^{2}2q$_{13}$=0.01
→sind>0.55
(33deg)

large sin^{2}2q$_{13}$
→sind>0.25
(14deg)

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

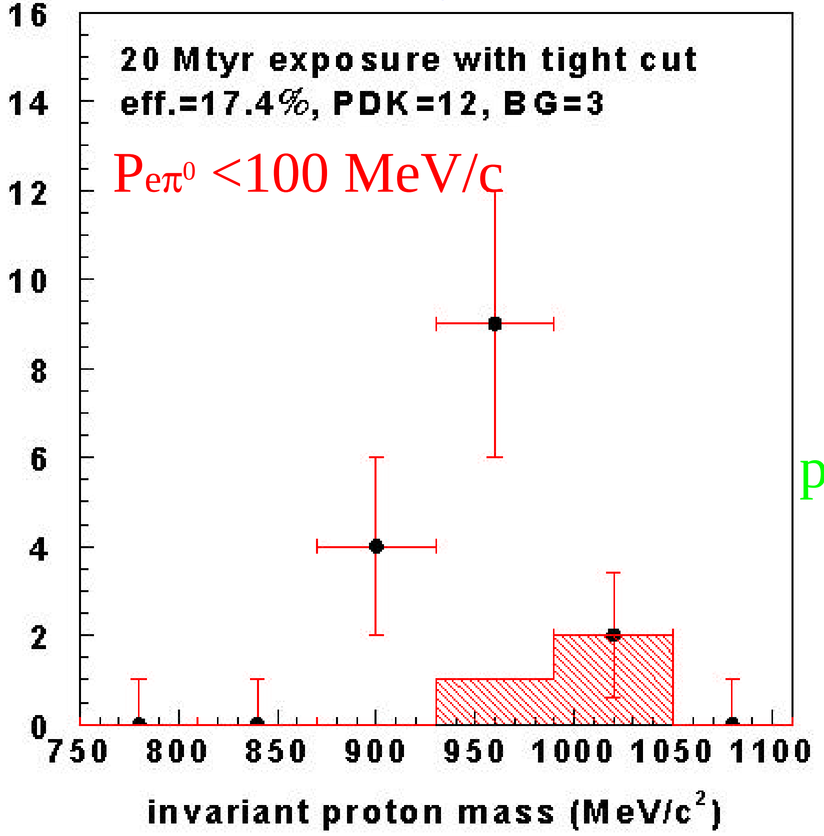


π^0 background has to be understood with 2% level.

(ν physics at a front detector)

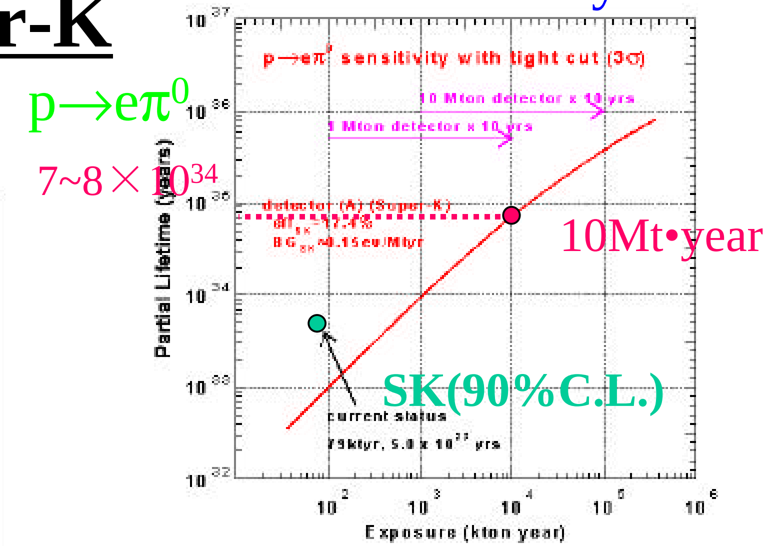
Proton Decay at Hyper-K

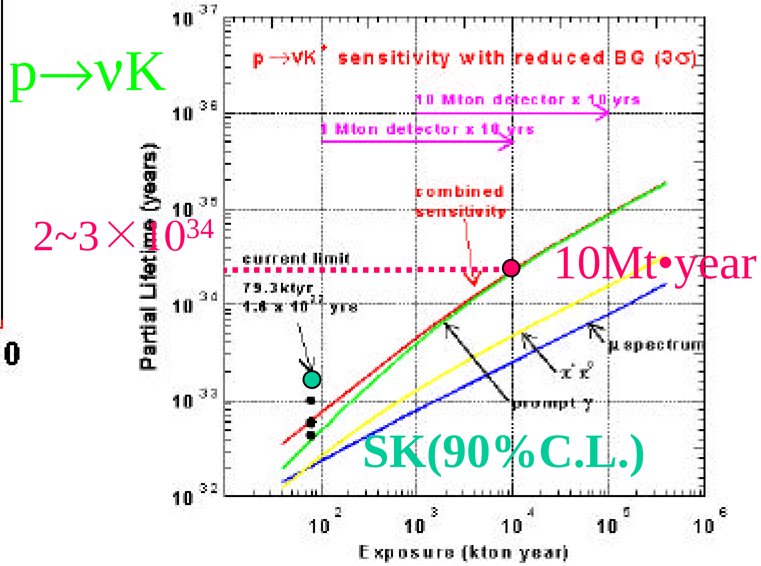
20Mt•year



$M_{e\pi^0}$ (MeV/c^2)

3σ discovery





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, and we need your STRONG support to put the experiment on track.
- The features of the experiment are:
  - MW class 50 GeV proton accelerator (0.77MW $\rightarrow$ 4MW)
  - ~1GeV Narrow band neutrino beam at the oscillation maximum (L=295km).
  - Gigantic Water Cherenkov detectors with/ neutrino energy reconstruction by quasi-elastic interaction. (22.5kton $\rightarrow$ 1000kton)

Physics Reach (see hep-ex/0106019)

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

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

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

  $\nu_\mu \to \nu_e$: $\sin^2 2\theta_{13} < 0.006$ (90% CL)

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

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

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

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

  $\nu_\mu \to \nu_e$ vs $\overline{\nu_\mu} \to \overline{\nu_e}$: $|\delta| > 20°$ (3σ discovery)

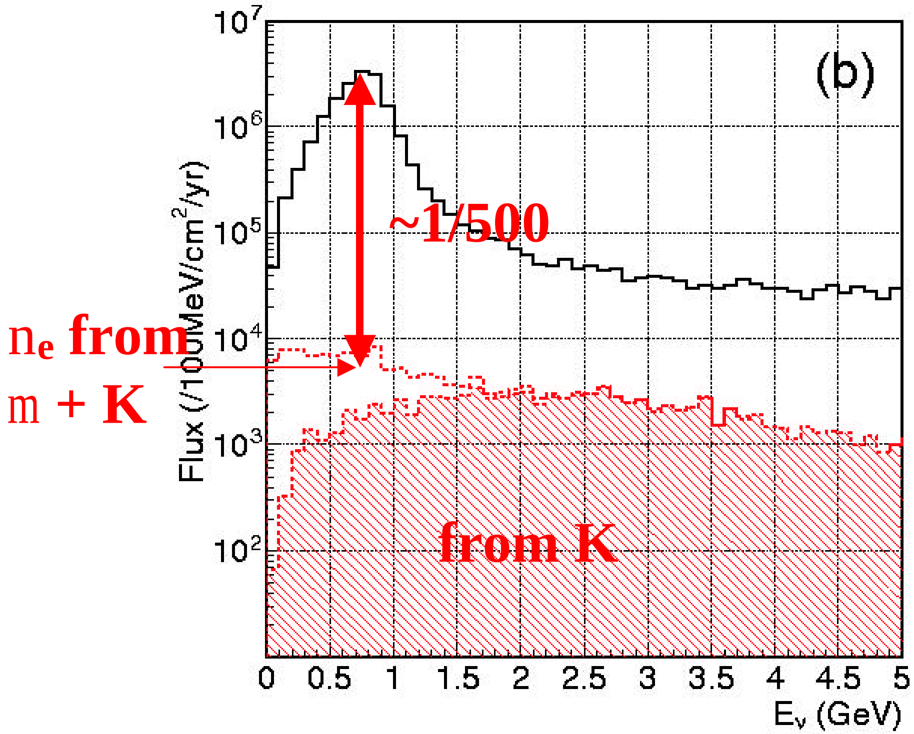
  at ($\Delta m_{12}^2 = 5 \times 10^{-5} eV^2$, $\Delta m_{23}^2 = 3 \times 10^{-3} eV^2$)

  $\tau_{proton} \cdot B(p \to e\pi^0, \nu K) > 10^{35}$ years

Supplement

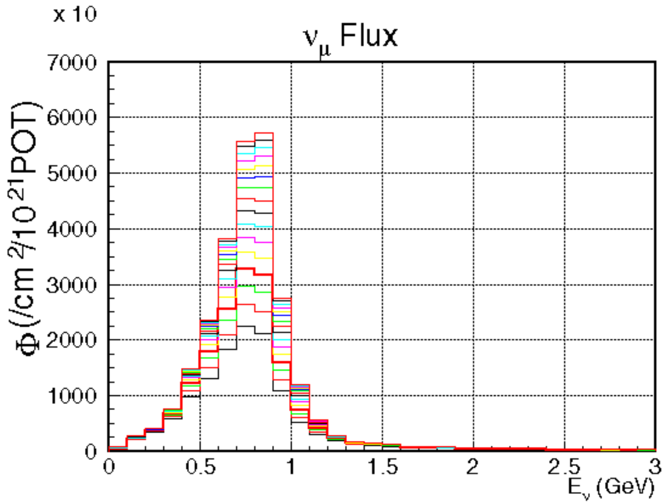
n$_e$ contamination in the beam

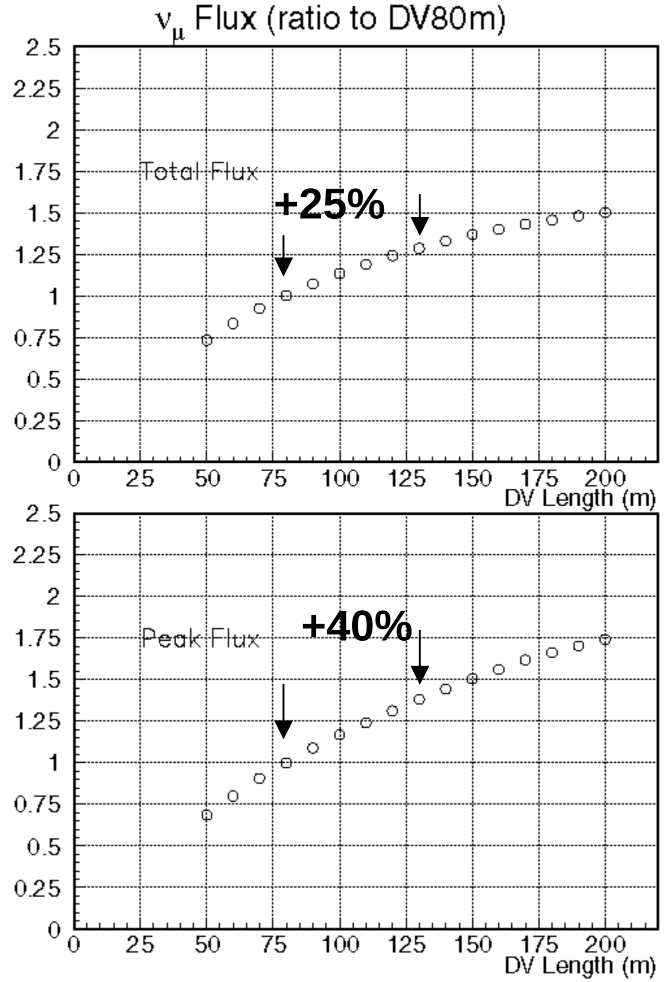
Off-Axis Beam



Intrinsic background: ν_e / ν_μ (peak) ~ 0.002 (0.005 for $\sin^2 2\theta_{13}$)

Beam improvement: decay pipe len

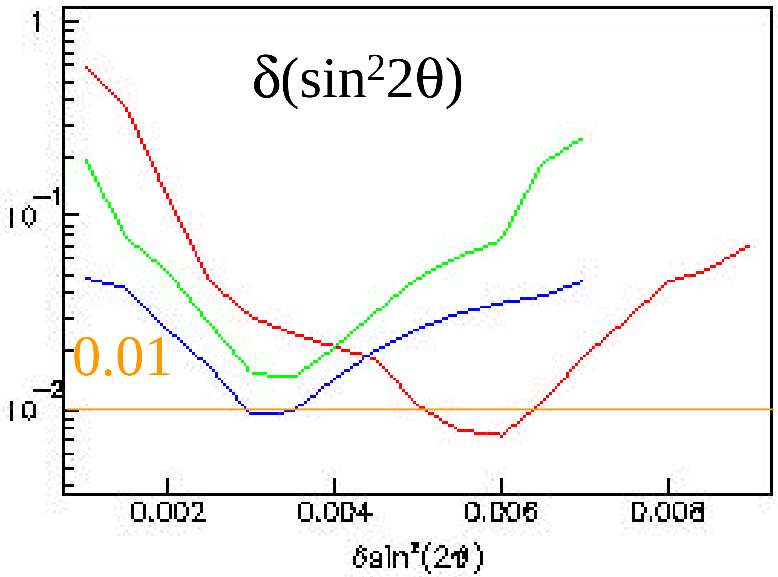


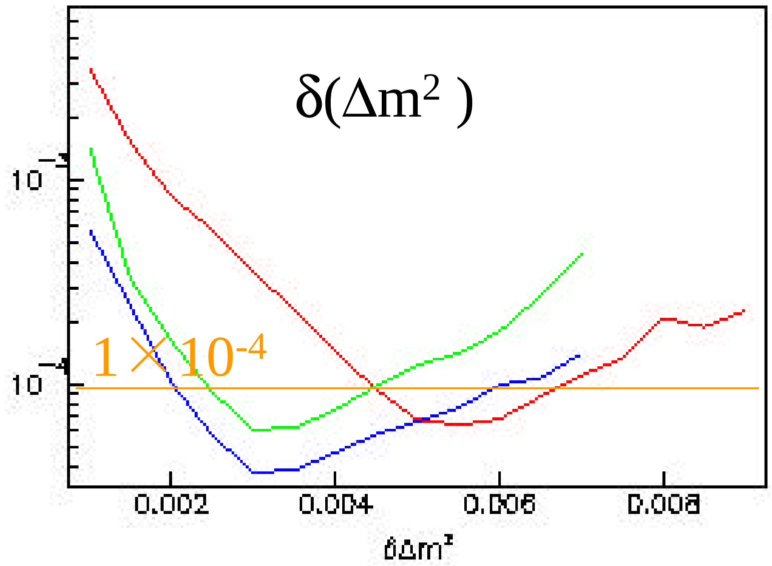


Improve statistics
HE tail -10% relative

5 years precision

NBB-3GeVπ, OAB-2degree, NBB-1.5GeVπ





$\delta(\sin^2 2\theta) \sim 0.01$ in 5 years

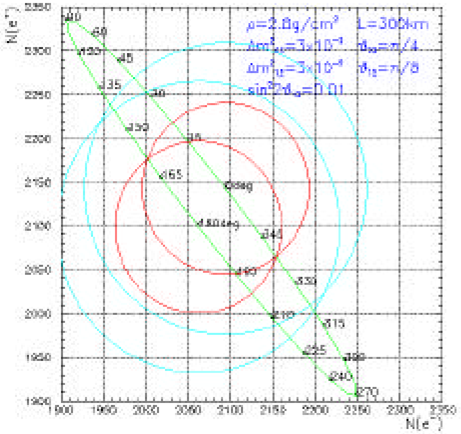
$\delta(\Delta m^2) \sim < 1 \times 10^{-4}$ in 5 years

q_{13}, Dm_{12} dependence for CP sensitivity

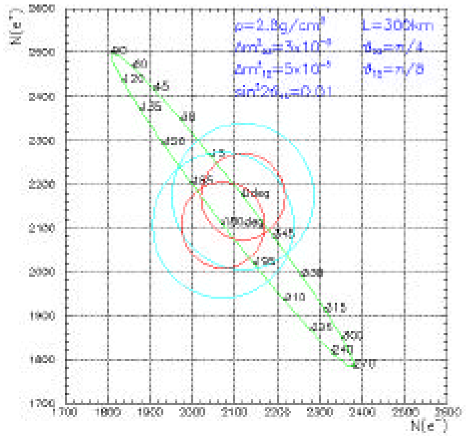
$$A_{CP} \propto \Delta m_{12}{}^2 / \sin^2 2q_{13}$$

- **NO** θ_{13} dependence for $\sin^2 2\,\theta_{13} > 0.01$
  - For $\sin^2 2\,\theta_{13} < 0.01$, there is an effect of background
- $\Delta m_{12}{}^2$ dependence ($\Delta m_{12}{}^2 >$ $2\sim 3 \times 10^{-5} eV^2$)

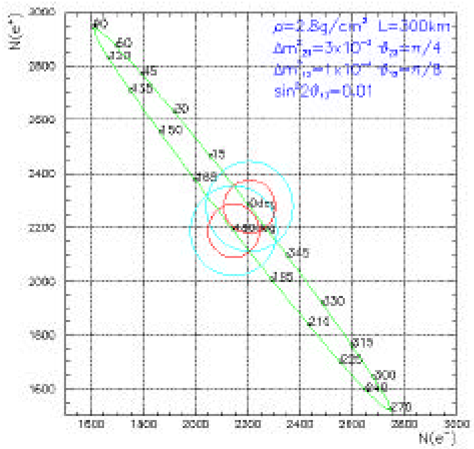
$\Delta m_{12}{}^2 = 3 \times 10^{-5} eV^2$



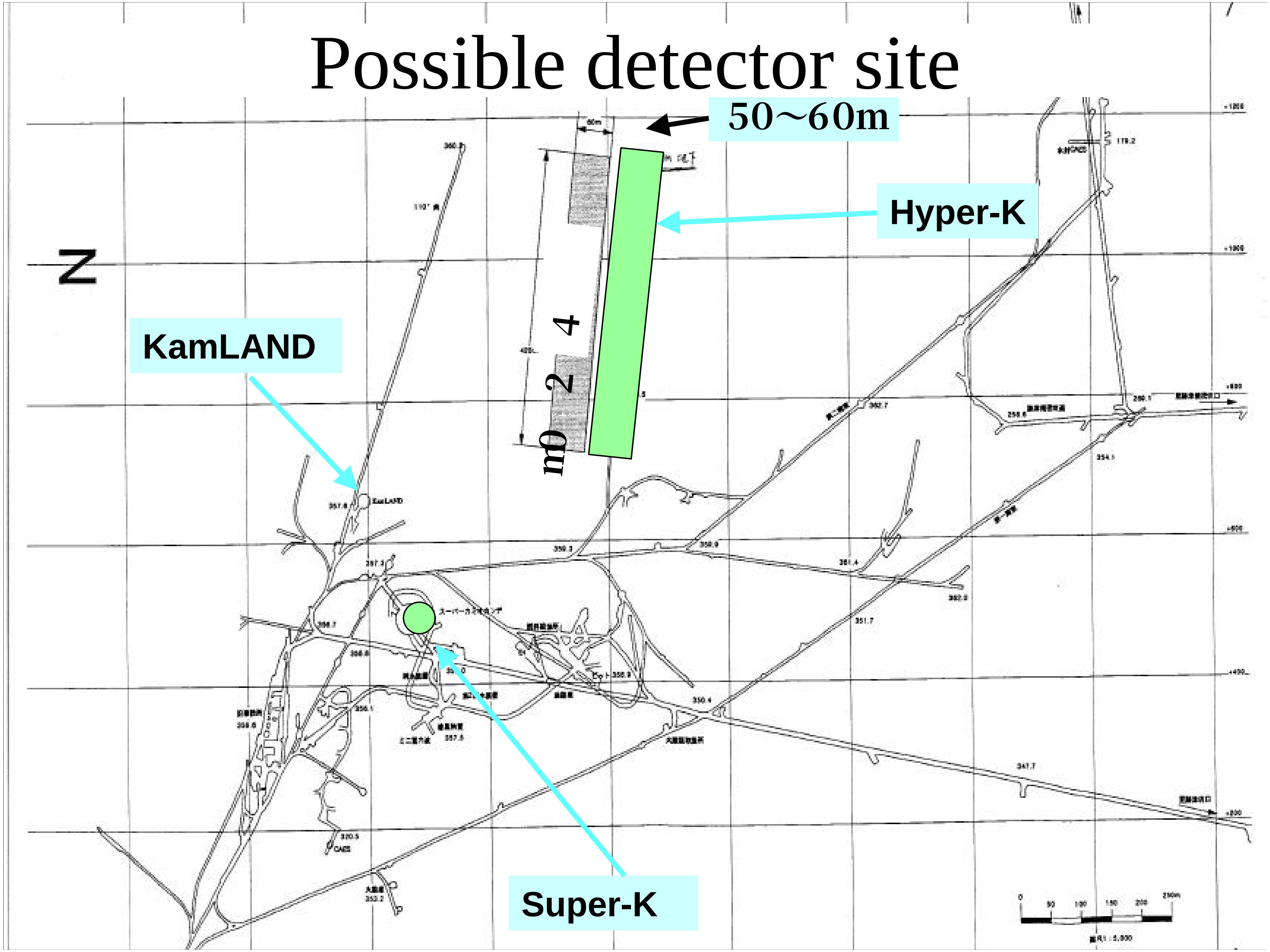
$\Delta m_{12}{}^2 = 5 \times 10^{-5} eV^2$



$\Delta m_{12}{}^2 = 10 \times 10^{-5} eV^2$



Possible detector site



http://www-sk.icrr.u-tokyo.ac.jp/doc/news/appeal.html

By Prof. Totsuka

We will rebuild the detector. There is no question. The strategy may be the following two steps, which will be proposed and discussed among my colleagues.

1. Quick restart of the K2K experiment.

(1)We will clear the safety measures which may be suggested by the committees, (2) reduce the number density of the photomultiplier tubes by about a half, (3) use the existing resources, (4) resume the K2K experiment as soon as possible; the goal may be within one year.

2. Preparation for the JHF-Kamioka experiment.

(1)Restore the full Super-Kamiokande detector armed with the state-of-the-art techniques. (2) The detector will be ready by the time of the commissioning of the JHF machine.

To achieve our objective is formidable but we are determined to do so. We certainly need your encouragement, advice and help. I should appreciate it very much if you could support our effort as you have kindly done so before.