Neutrino experiments

2002年2月22日
第2回素粒子原子核研究計画委員会
京都大学大学院理学研究科
西川公一郎

1. **New findings**
   - **non-zerro neutrino mass !**
   - **Atmospheric ν_μ deficiency : likely $\nu_\mu \rightarrow \nu_\tau$**
   - **SNO+SK Appearance of non- ν_e components**
   - **All solar exp. LMA solution likely**
   - **No sign of sterile in atm., solar**
2. **What should be (shall be, can be) done next**

JHF Neutrino Working Group
→ International collaboration

ICRR/Tokyo-KEK-Kobe-Kyoto-Tohoku-TRIUMF

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A.Konaka (TRIUMF, CANADA)

Dec.99: Working group formed.
Mar.00: Letter of Intent prepared (http://neutrino.kek.jp/jhfnu)
Now : Working to prepare a proposal

Atmospheric, solar, and K2K

- **Atmospheric**
  - ✓ ν_μ–ν_τ oscillation
  - ✓ $1.6\times10^{-3} < \Delta m^2_{23} < 4\times10^{-3}\text{eV}^2$ $\sin^2 2\theta_{23} > 0.90$ (90%C.L.)
- **Solar**
  - ✓ LMA likely Large θ_{12} , Δm^2_{12}
- **No sign of sterile in both solar, atmospheric**
- **K2K**
  - ✓ Rate ~30% decrease integrated over K2K spectrum
  - ✓ Spectrum analysis → Oscillation pattern
  - ➢ Energy measurement
  - ➢ Far/near

Central issue in ~5 years ago

- Unambiguious sign of oscillation
  1. ν_τ appearance
  2. oscillation pattern
- SSM independent signatures of oscillation in solar ν
  - NC measurements
  - Spectrum distortion
  - day/night effect
- LSND effect
  - more than 3 neutrinos?

Near future

- Appearance of ν_τ : sign of oscillation
  - confirmation at CERN-Gran-sasso
- LMA soultion in solar ν
  - Kamland, Borexino, Low E measurements (SK, New detectors……)
- LSND
  - Mini-BooNE, just starting
- Spectrum distortion in K2K

- What is next step ?

Next goal

- 新しい現象 （物質の起源（**B≠0**））
  - 粒子-反粒子の同等性の破れ
    - **Existence of CP-violation in lepton sector**
  - バリオン数の破れ
    - **Proton decay**
  - (熱平衡の破れ―cosmology）
- 物質とは
  - レプトン⇔クォーク, **generation**
  - **(near) GUTs scale (10^{10} ~ 10^{16} GeV) physics**
    - **Small neutrino mass ~ m^2_{weak}/M**
    - **Mass-Interaction : mixing ($\theta_{13} << \theta_{12}, \theta_{23}$ or $\theta_{13} < \theta_{12}, \theta_{23}$?)**

3 Generations MNS matrix

- 3 angles and 1 phase

$$U = \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13}e^{i\delta} \end{pmatrix} \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}$$

solar reactor atmospheric

$\nu_e \to \nu_x$ with $(m_2^2 - m_1^2)$ $\nu_e \to \nu_x$ with $(m_3^2 - m_1^2)$ $\nu_\mu \to \nu_\tau$ with $(m_3^2 - m_2^2)$

$\nu_\mu \to \nu_e$ with $(m_3^2 - m_1^2)$

NOT OBSERVED

δ : CP Violation in Lepton Sector

(Why $\nu_\mu \rightarrow \nu_e$)

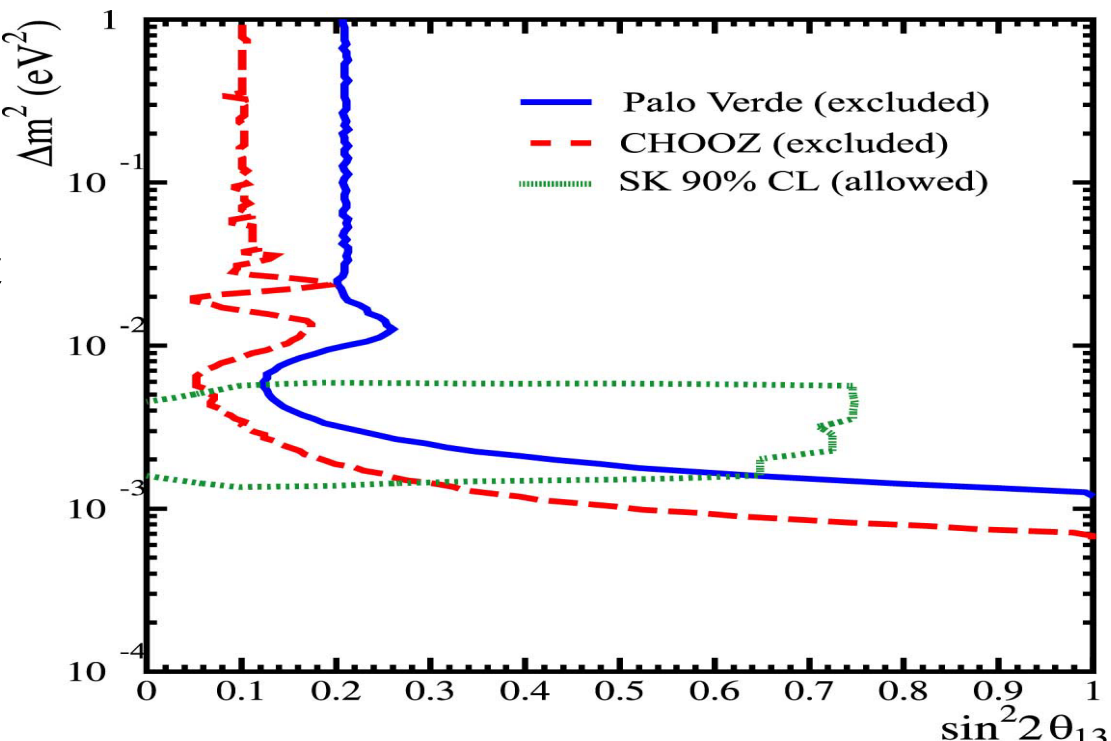
$$P_{\alpha\beta} = \delta_{\alpha\beta} - 4\sum_{j>i} \mathrm{Re}(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j}) \sin^2 \frac{(m_j^2 - m_i^2)L}{4E_\nu}$$

$$\mp 2\sum_{j>i} \mathrm{Im}(U^*_{\alpha i}U_{\beta i}U_{\alpha j}U^*_{\beta j}) \sin \frac{(m_j^2 - m_i^2)L}{2E_\nu}$$

$=0$ for $\alpha=\beta$ $\rightarrow$ appearance exp!

➢ $\nu_\mu \rightarrow \nu_e$

Current limit



Meaning of recent developments toward CPV search

- **CPV $\propto$ $\sin\theta_{12}$ $\sin\theta_{23}$ $\sin\theta_{13}$ Δm^2_{12} (L/E) $\sin\delta$**
  - **Solar LMA solution (large Δm^2_{12}, large θ_{12})**
  - **Near max. mixing in atmospheric ($\theta_{23}\sim\pi/4$)**

Precision second generation experiment

- θ_{13} $(\nu_\mu \rightarrow \nu_e) \rightarrow$ **CP violation**
- **Oscillation pattern , θ_{23} , Δm^2**

Sub-GeV Beam + Large water Cherenkov detector

K2K has proved

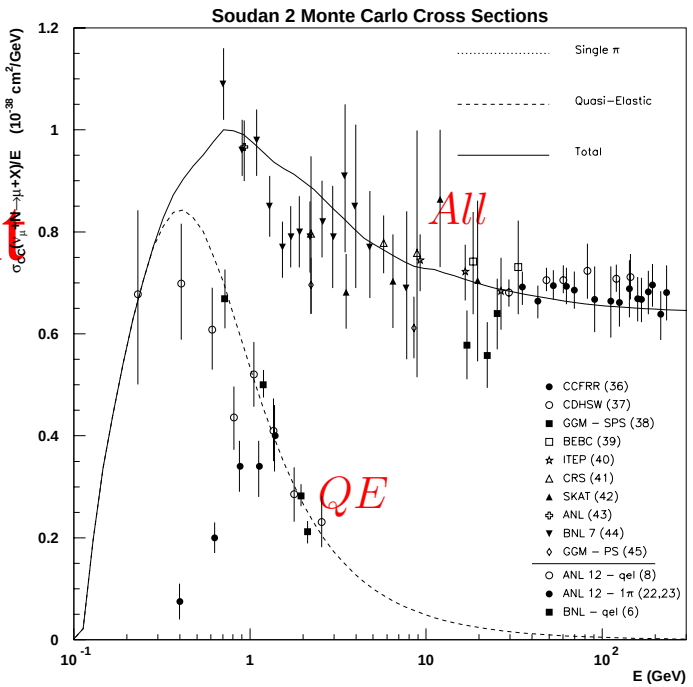
- ✓ **Beam control-ability and stability**
- ✓ **Event reconstruction (single e, μ)**
- ✓ **Energy reconstruction**
- ✓ **Event selection (GPS timing)**
- ✧ **Must be improved Far/Near, backgrounds**

Beam energy

- ✓ Low energy beam
  - ✧ Region of interest $\Delta m^2 = 2 \sim 4 \times 10^{-3} eV^2$
  - ✧ Kamioka at 295 km
  - ✧ Good low energy detector
- ✧ Neutrino energy measurement

  Quasi-elastic $\Leftrightarrow \mu + E_{had}$

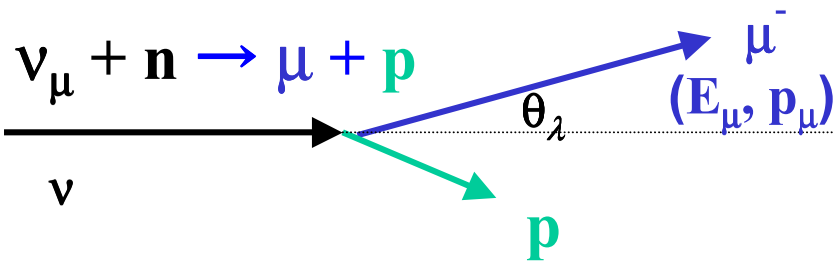
  - ➢ $E \leq 1GeV$ **$\sigma(E\nu) \sim 50$ MeV**
  - ✧ Cross section
    - ➢ $E \geq 0.3$ GeV

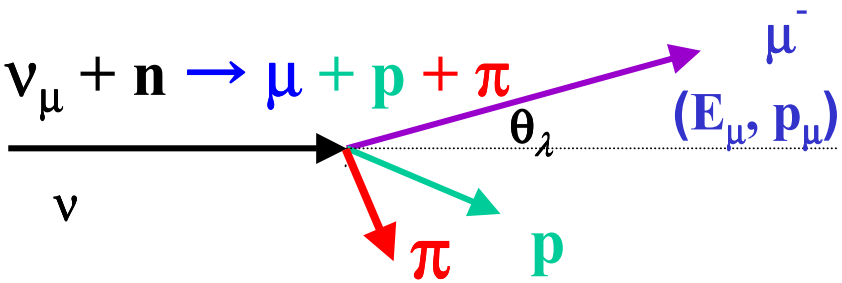


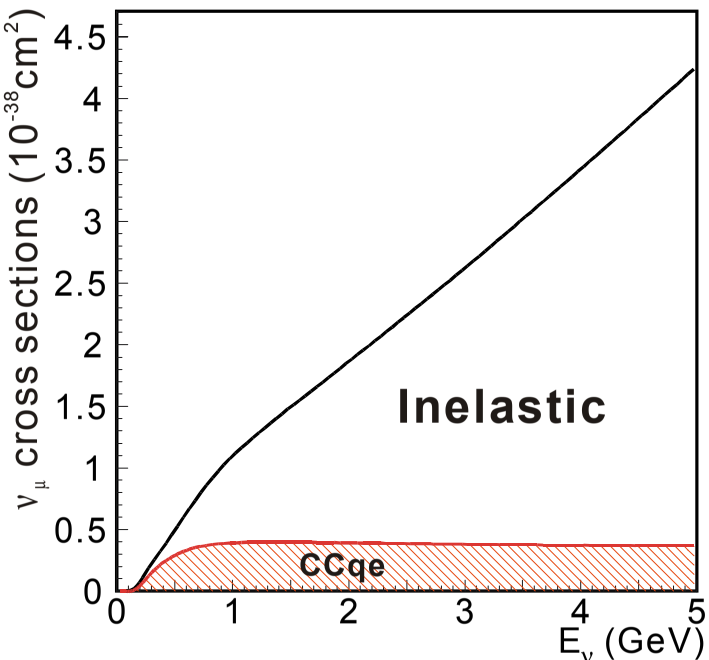
Neutrino Energy measurement with 1-ring mu-like

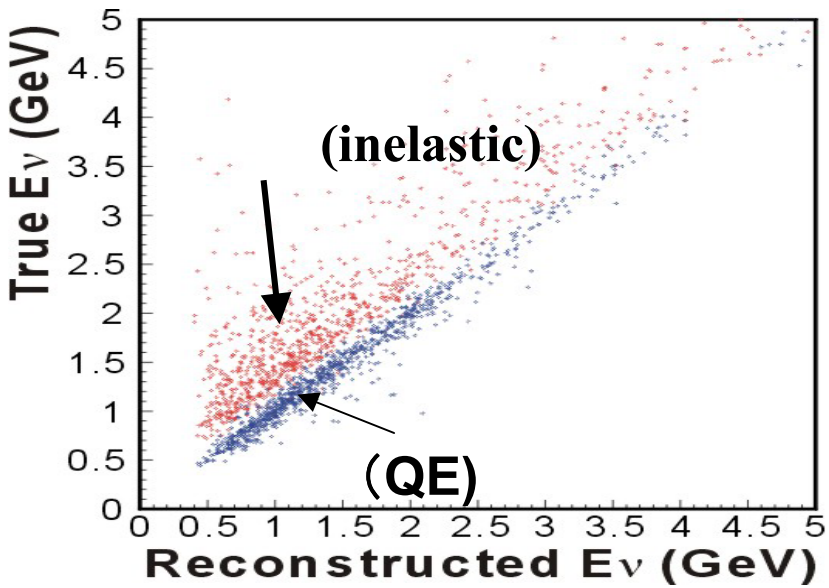
CC quasi elastic reaction

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









Beam energy

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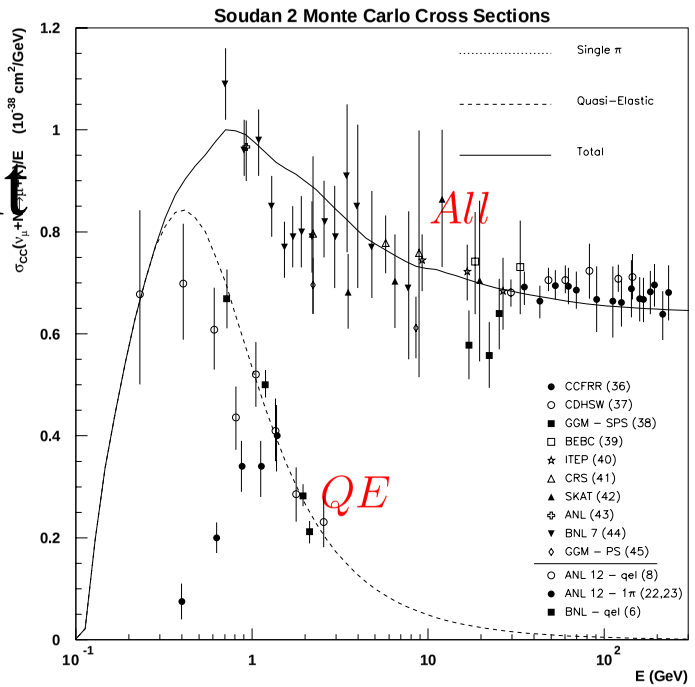
  - ✧ Region of interest $\Delta m^2 = 2 \sim 4 \times 10^{-3} eV^2$
  - ✧ Kamioka at 295 km
  - ✧ Good low energy detector
- ✧ Neutrino energy measurement

  Quasi-elastic $\Leftrightarrow \mu + E_{had}$
  - ➢ $E \leq 1GeV$
  - ✧ Cross section
    - ➢ $E \geq 0.3$ GeV

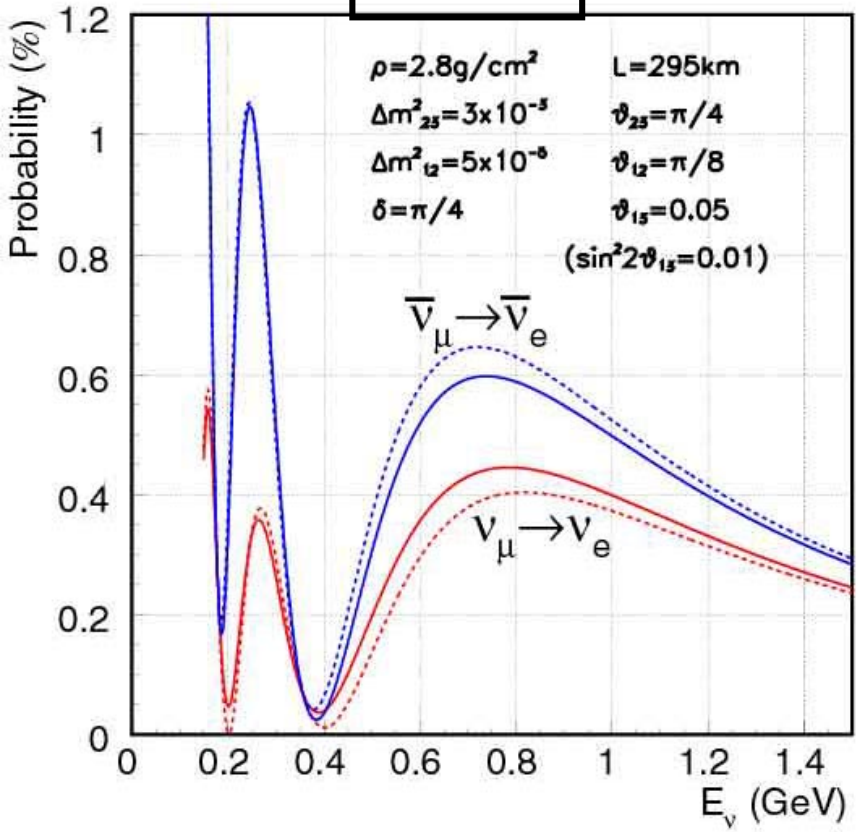
σ(Eν)~50 MeV



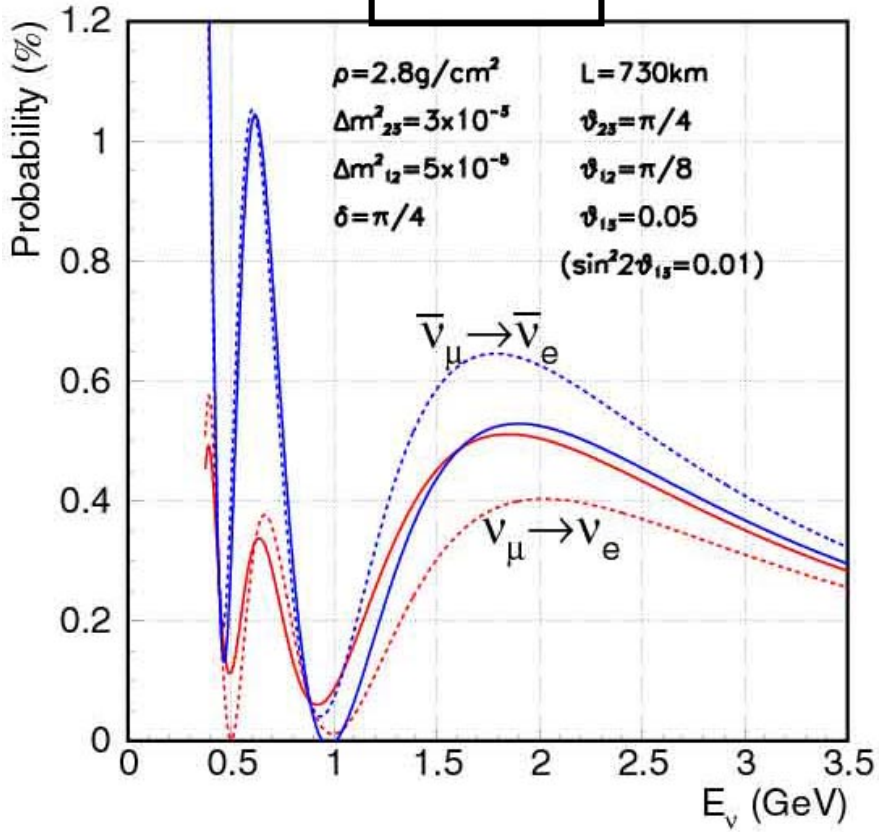
✧ Better separate matter effect

$\nu_\mu \rightarrow \nu_e$ oscillation probability

295km



730km



Solid line: w/ matter
Dashed line: w/o matter

Small Matter Effect at 295km.

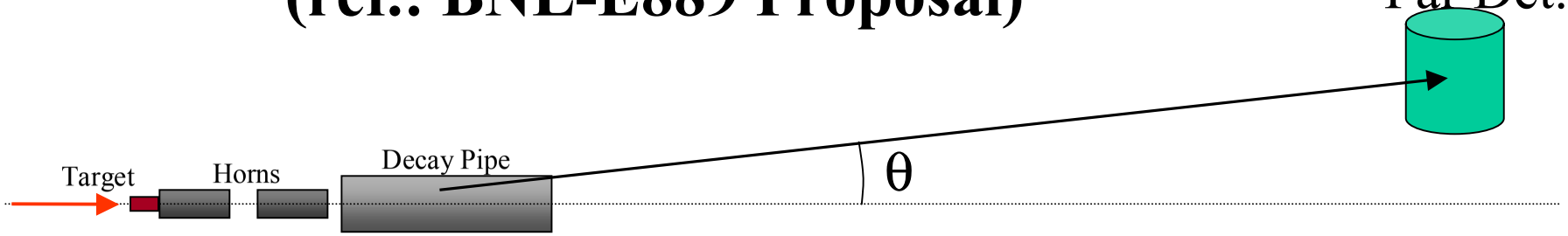
Requirements and design of experiment

- Highest low energy beam with small HE tail
  - Off-axis beam (2 ~ 3 degree)
- Ambiguity of ν and anti-ν interactions
  - study at near detector with narrow band beam at near detector (@ 280m from production target)
- Near/Far extrapolation
  - ~2km detector

➢ Three detectors configuration

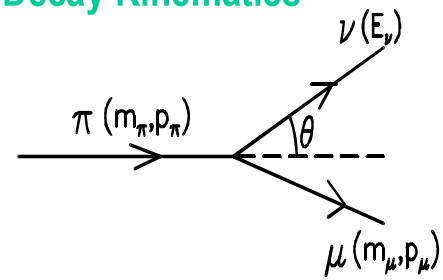
➢ 280m, 2km, and 295km

Off Axis Beam
(ref.: BNL-E889 Proposal)

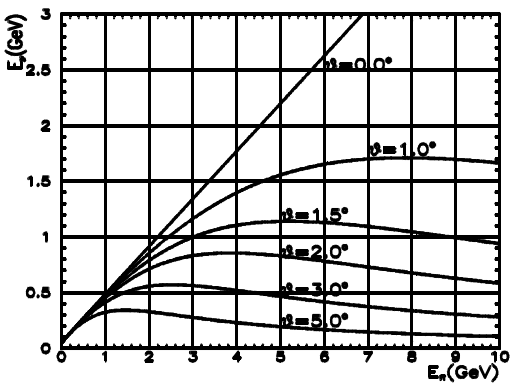


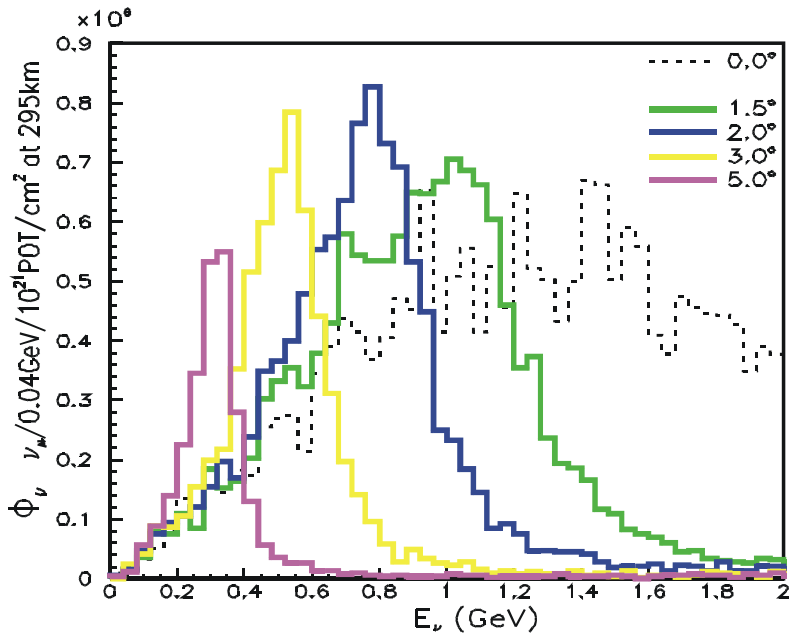
WBB w/ intentionally misaligned beam line from det. axis

Decay Kinematics



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





- **Highest intensity at low energy 4500 int./22.5kt/year (10^7 sec.)**
- **Contamination ν_e:0.8%(0.3% @ peak)**

Requirements and design of experiment

- Highest low energy beam with small tail
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➢ Three detectors configuration

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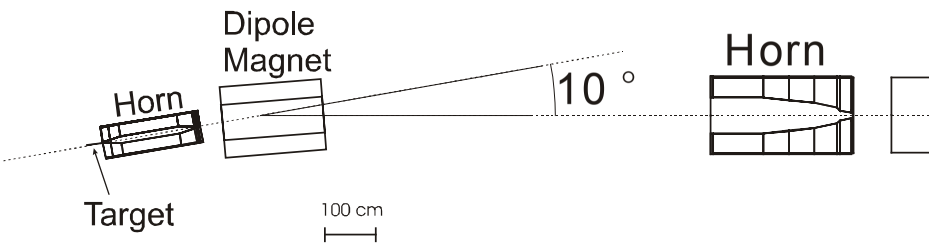
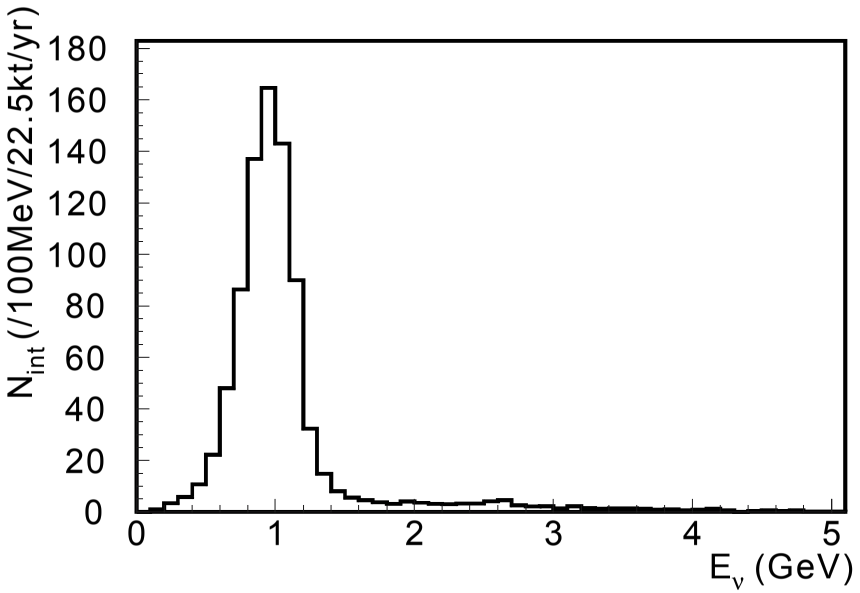
Narrow Band Beam

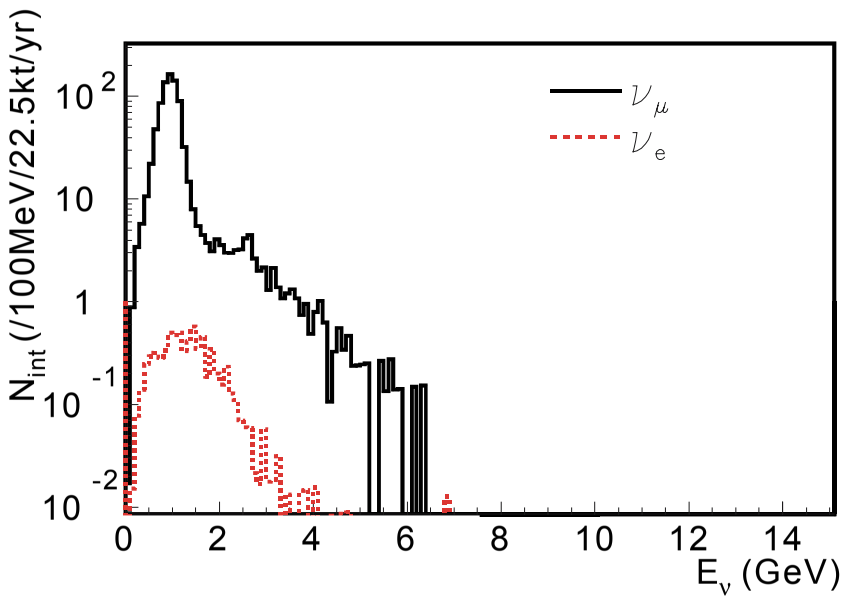




~1 ν_μ int./100 ton/spill @280m from target

- **E_ν can be changed easily**
- **neutrino interaction studies**
- **low intensity**

ν_e:0.8%(0.3% @ peak)



yet to be optimized

Requirements and design of experiment

- Highest low energy beam with small tail
  - Off-axis beam (2 ~ 3 degree)
- Ambiguity of ν and anti-ν interactions
  - study at near detector with narrow band beam at near detector (@ 280m from production target)
- Near/Far extrapolation
  - ~2km detector

➢ Three detectors configuration

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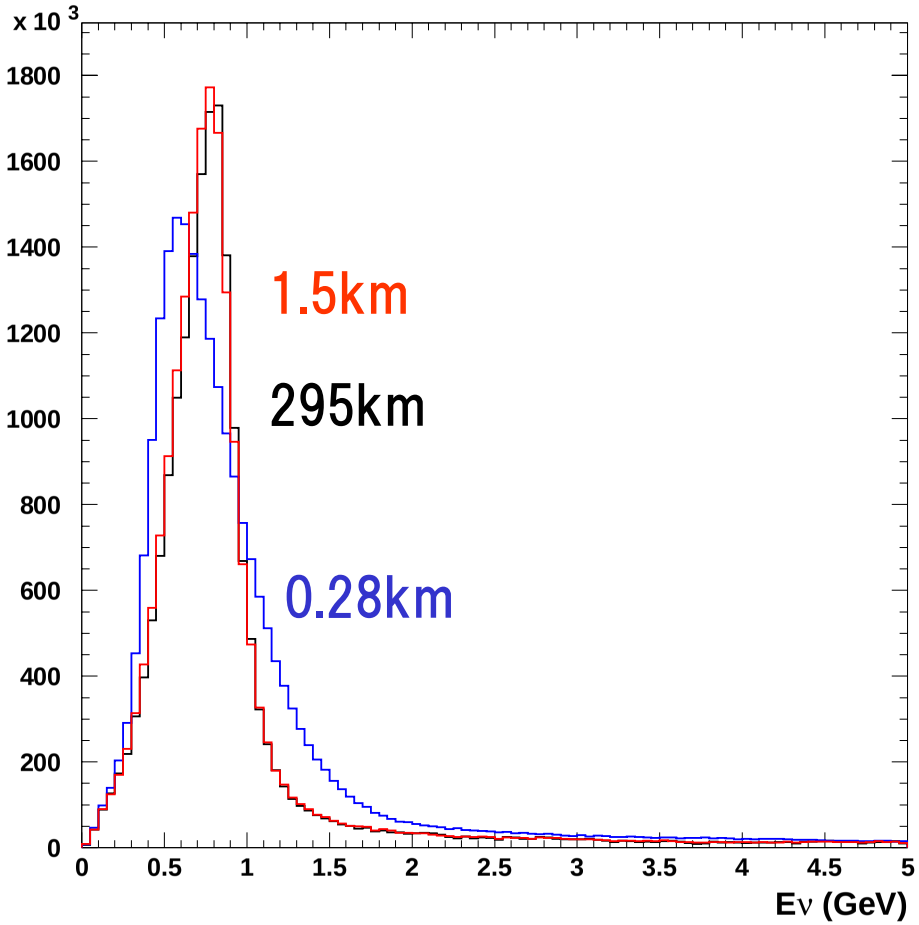
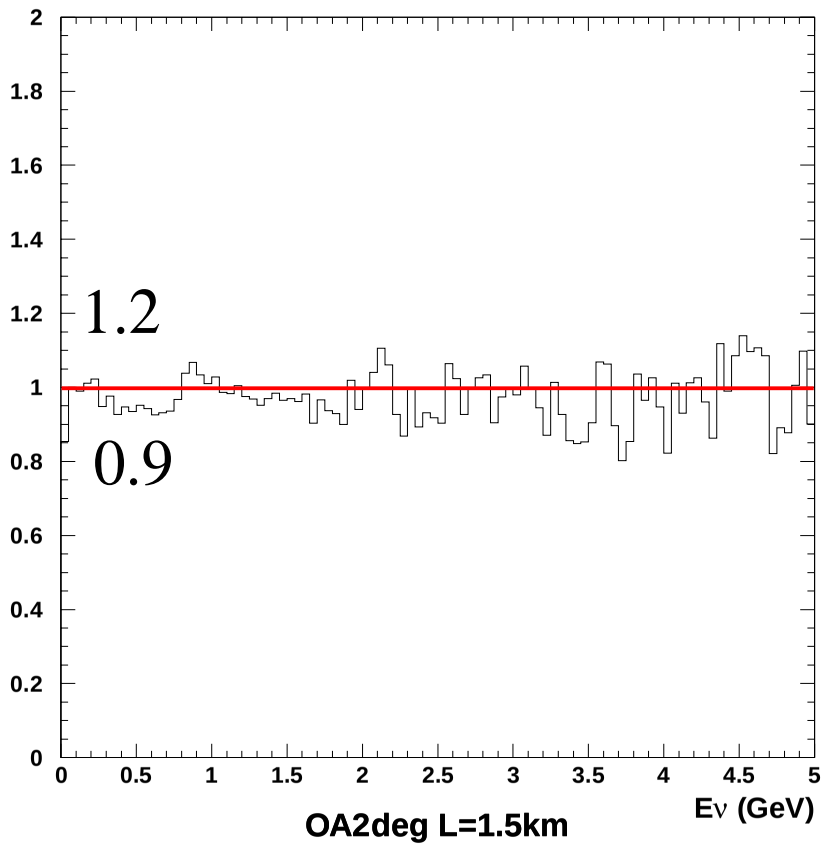
スーパーカミオカンデと前置検出器でのニュートリノのスペクトルの比較



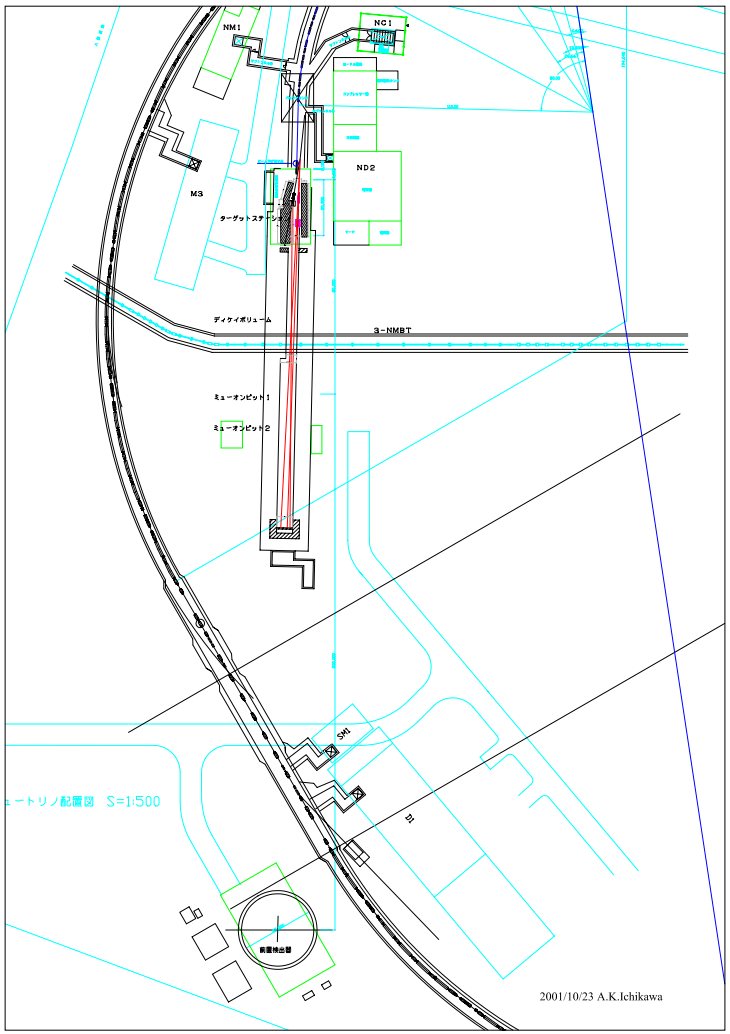


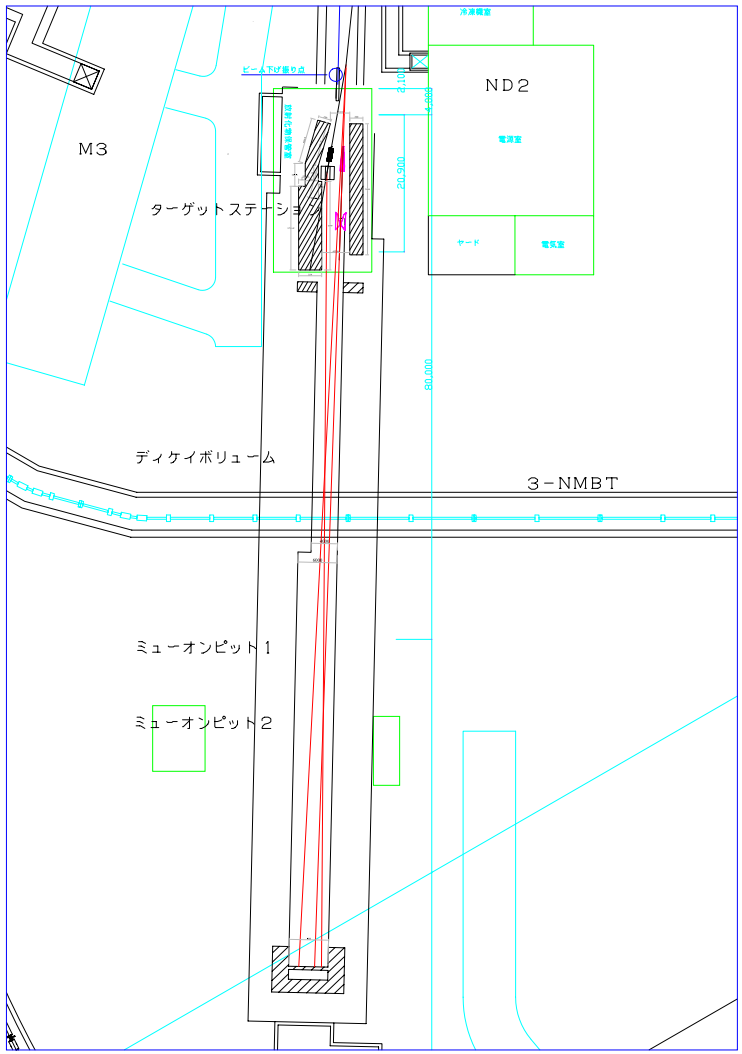
0.28 km/295 km , func. of Eν

ニュートリノエネルギー

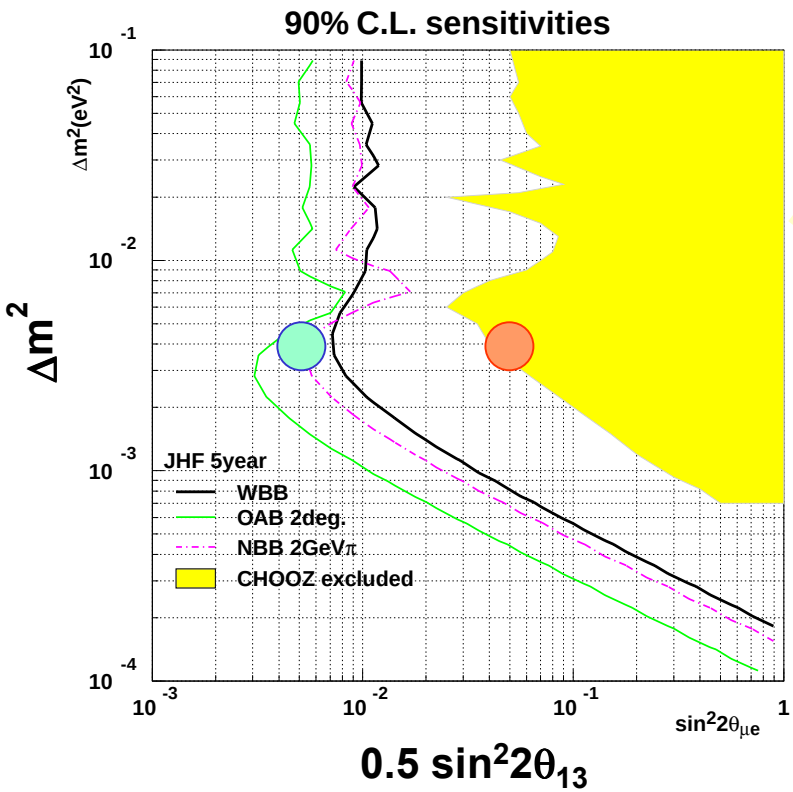
Neutrino beam-line at JHF

2-3 degree off-axis and low intensity narrow band





$\sin^2 2\theta_{13}$ from appearance experiment $\nu_e + n \rightarrow e + p$



Work in progress

Off axis 2 deg, 5 years

$\sin^2 2\theta_{13}$	Background in Super-K (as of Oct 25, 2001)					Signal	Signal + BG
	ν_μ	ν_e	$\bar{\nu}_\mu$	$\bar{\nu}_e$	total		
0.1	12.0	10.7	1.7	0.5	24.9	114.6	139.5
0.01	12.0	10.7	1.7	0.5	24.9	11.5	36.4

Off axis 2 deg, 5 years

- **Sensitivity (goal) : Phase 1**

  $\delta \sin^2 2\theta_{23} \sim 0.01$
  $\sin^2 2\theta_{13} \sim 5 \times 10^{-3}$ (90% CL)
  $\delta \Delta m_{23}^2 \sim 1.5 \times 10^{-4} \mathrm{eV}^2$
  at ($\sin^2 2\theta = 1.0$, $\Delta m^2 = 3.2 \times 10^{-3} \mathrm{eV}^2$)

- Off−axis beam ~ 2 degree
  - decay volume 130m

- Narrow band beam (near only)
  - neutrino interaction studies

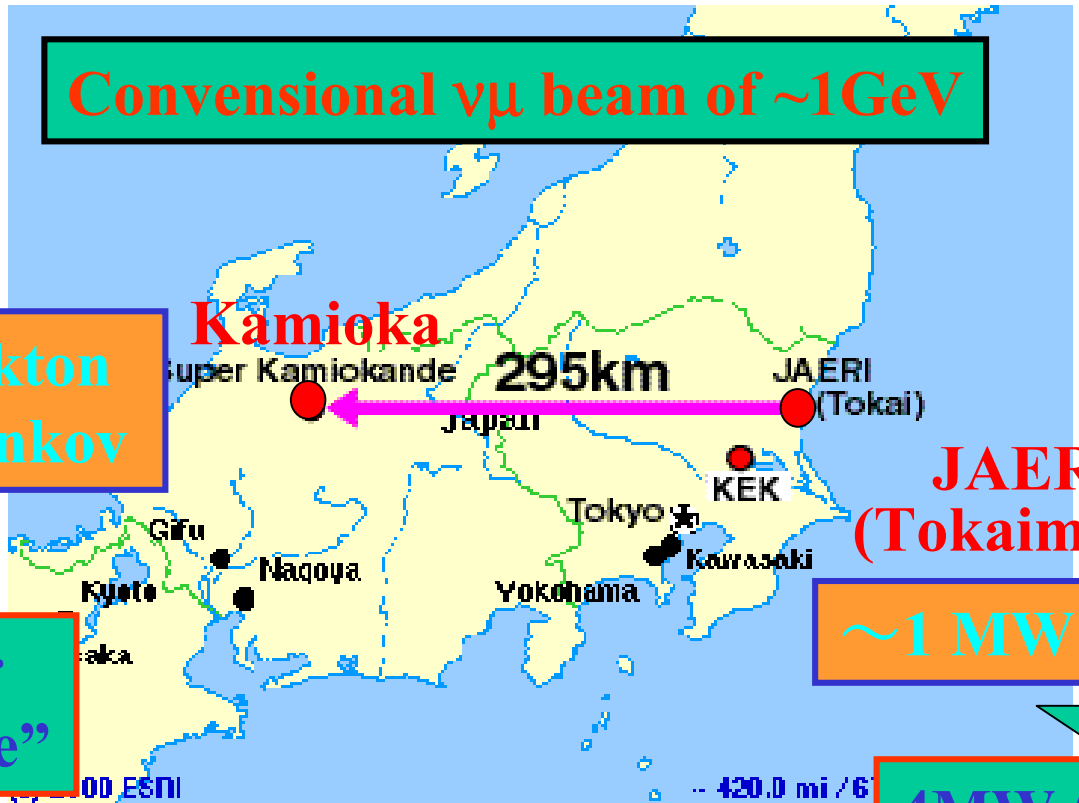
J.Wilkes' Table

(www.phys.washington.edu./~wilkes/NNO/)

Experiment / Property	SK	K2K	MINOS	ICARUS	OPERA	JHF-Kam	MONOLITH	ν-factory
				CNGS				
$\delta(\Delta m^2_{23})$ ±%	50	20	10	10	20	3.3	6	2
$\delta(\sin^2 2\theta_{23})$ ±%	5	5	5	5	?	1	4	2
Osc peak	X?	O*	O?	X(Oatm)	?	O	O	O
τ appear-ance	O?	X	O	O	O	X	O	O
$\sin^2 2\theta_{13}$	>0.1	>0.01	0.03	0.015	?	0.006	?	$1\sim3\times10^{-3}$
$\delta(\nu_s/\nu_\tau)$	0.2	X	0.05?	0.05	?	0.2	~0.2	0.01
ν decay	O?	~X	O	X(Oatm)	?	O	O	O
Sign of Δm^2	X	X	X	X	X	X	X	O
CP violation	X	X	X	X	X	O	X	O

On-going experiments

JHF-SK(HK) ν Experiment



Super-K: 50 kton Water Cherenkov

~Mt "Hyper Kamiokande"

JAERI (Tokaimura)

~1 MW 50 GeV PS

4MW 50GeV PS

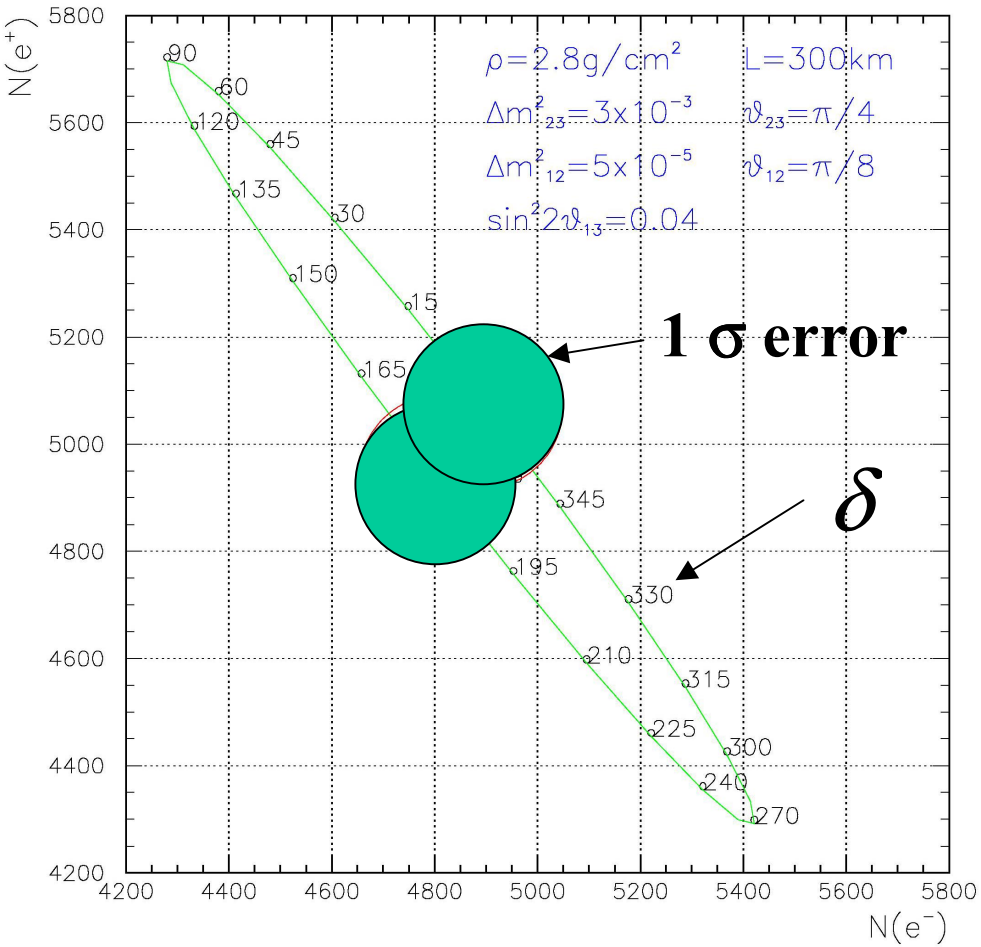
First Phase

- $\nu_\mu \rightarrow \nu_e$ appearance
- (Large CPV)
- $\nu_\mu \rightarrow \nu_x$ disappearance
- NC measurement

Second Phase

- CPV
- proton decay

Future prospect of CP−violation study



4 MW PS upgrade

Mton Hyper-Kam.

2 years for ν_μ

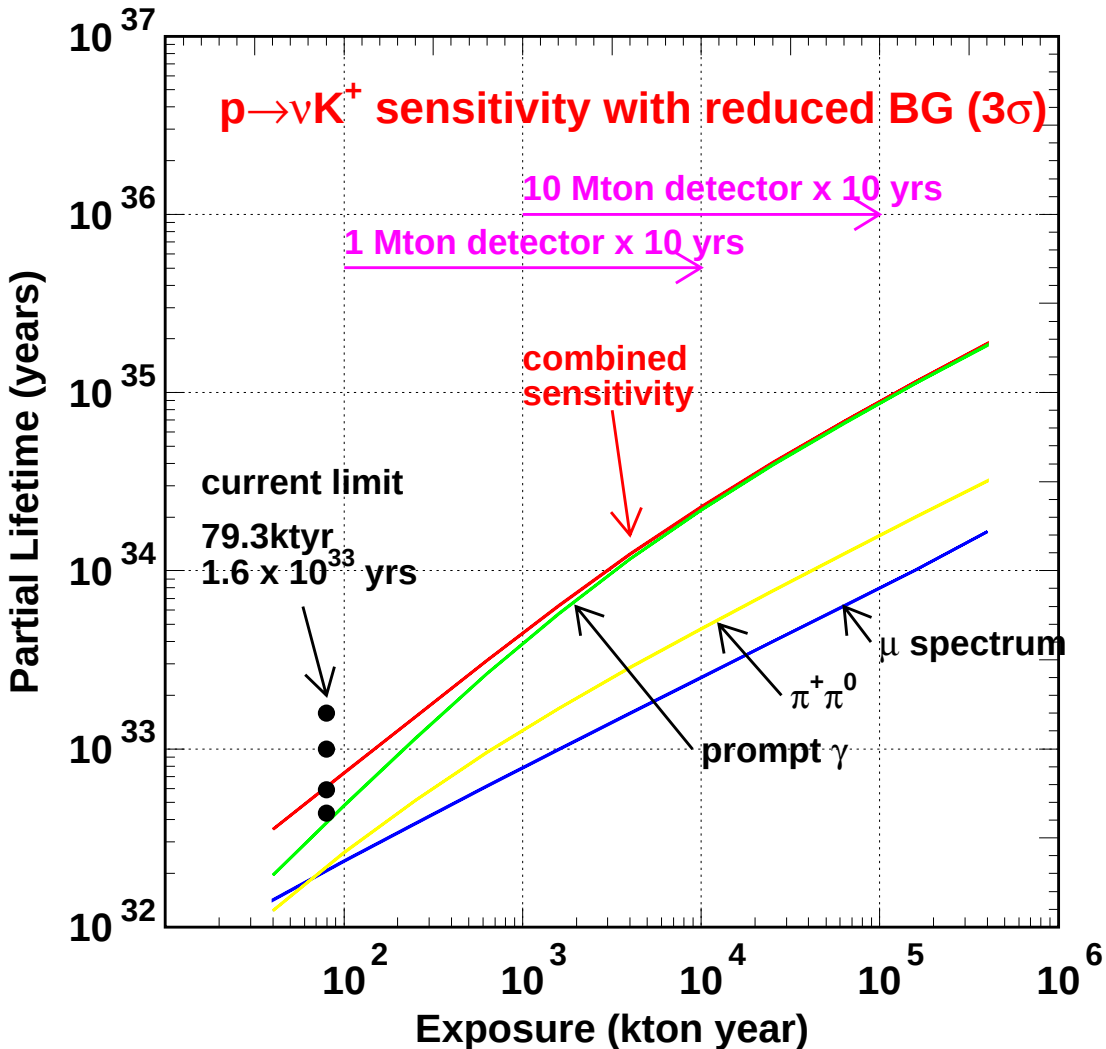
6 years for $\overline{\nu_\mu}$

Difference of ν_e appearance is the signal of CP violation

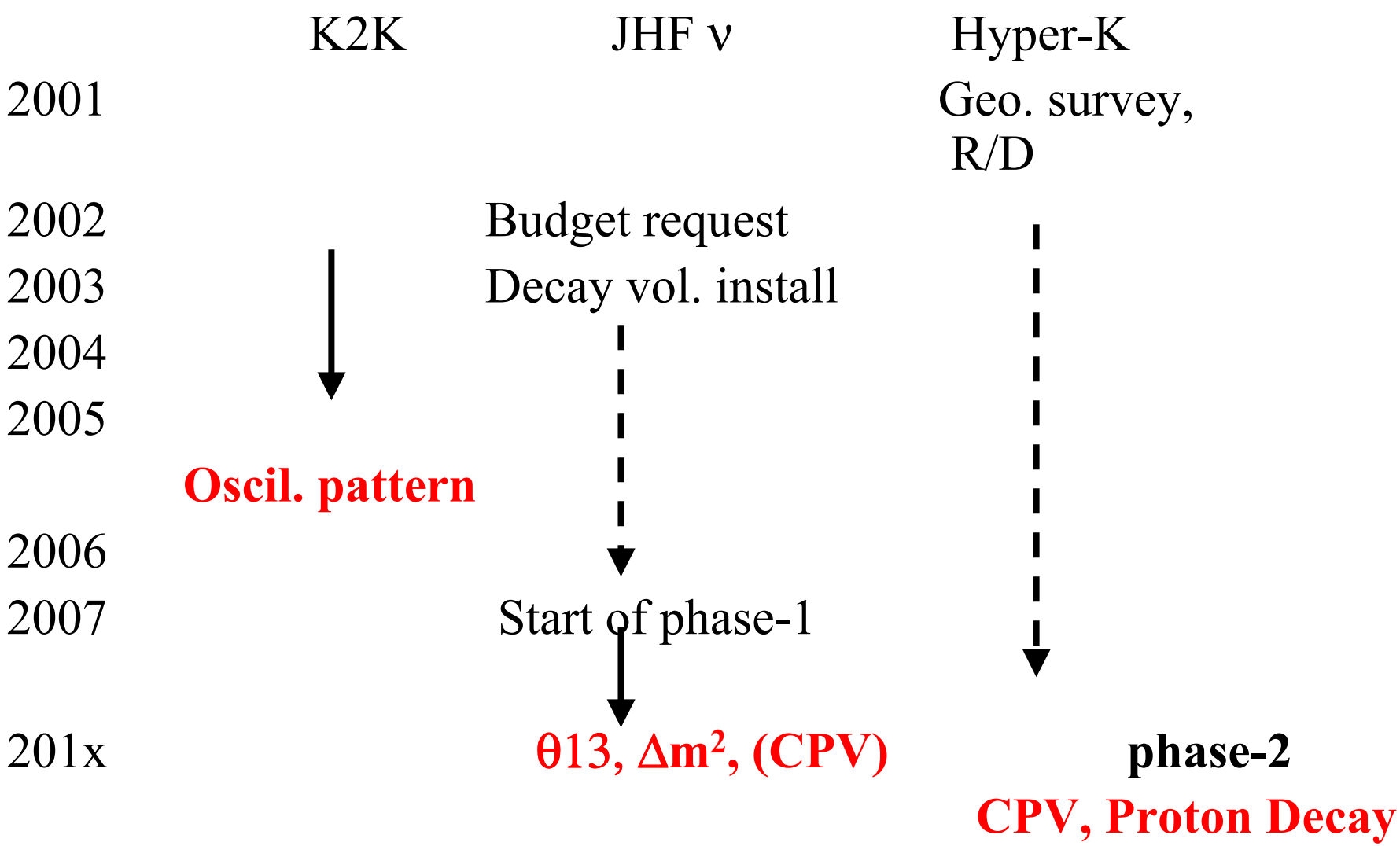
Sensitivity limit of νK^+

$^{16}O \rightarrow {}^{15}N^* + \nu + K^+$

γ(6MeV, prompt) $\nu + \mu^+$ (12ns delay)



Road Map


K2K
JHF ν
Hyper-K
2001
Geo. survey,
R/D
2002
Budget request
2003
Decay vol. install
2004
2005
Oscil. pattern
2006
2007
Start of phase-1
201x
θ13, Δm², (CPV)
phase-2
CPV, Proton Decay

End