2001年10月12日
KEK研究計画委

K2K実験

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1. K2K
    1. Motivation
    2. Experiment
    3. Results
    4. Future prospect
2. After K2K experiment(JHF-SK ν project)
3. Summary

Motivation

Evidence of osc. in atm. ν observation by SK (1998)

$$p = \sin^2 2\theta \cdot \sin^2(1.27\Delta m^2 L / E_\nu)$$

Neutrino Oscillation(2flavors)

$\Delta m^2 = (1.4\sim4) \times 10^{-3}$ eV^2
$\sin^2 2\theta > 0.89$
almost $\nu_\mu \rightarrow \nu_\tau$

K2K: definite confirmation of atm ν results/something new?

well defined flight length (=250 km)

well defined artificial pure ν_μ beam

	L	*E*	*E/L*	ν_μ/ν_e
Atm ν	10～10^{4}km	<5GeV	0.5～5x10^{-4}	2/1
K2K	250km	～1GeV	4x10^{-3}	99/1

K2K Overview

- ν_μ (99%) beam
- $\langle E_\nu \rangle \sim$ **1.3GeV**
- **Near detector**

  @300m
- **Far detector**:

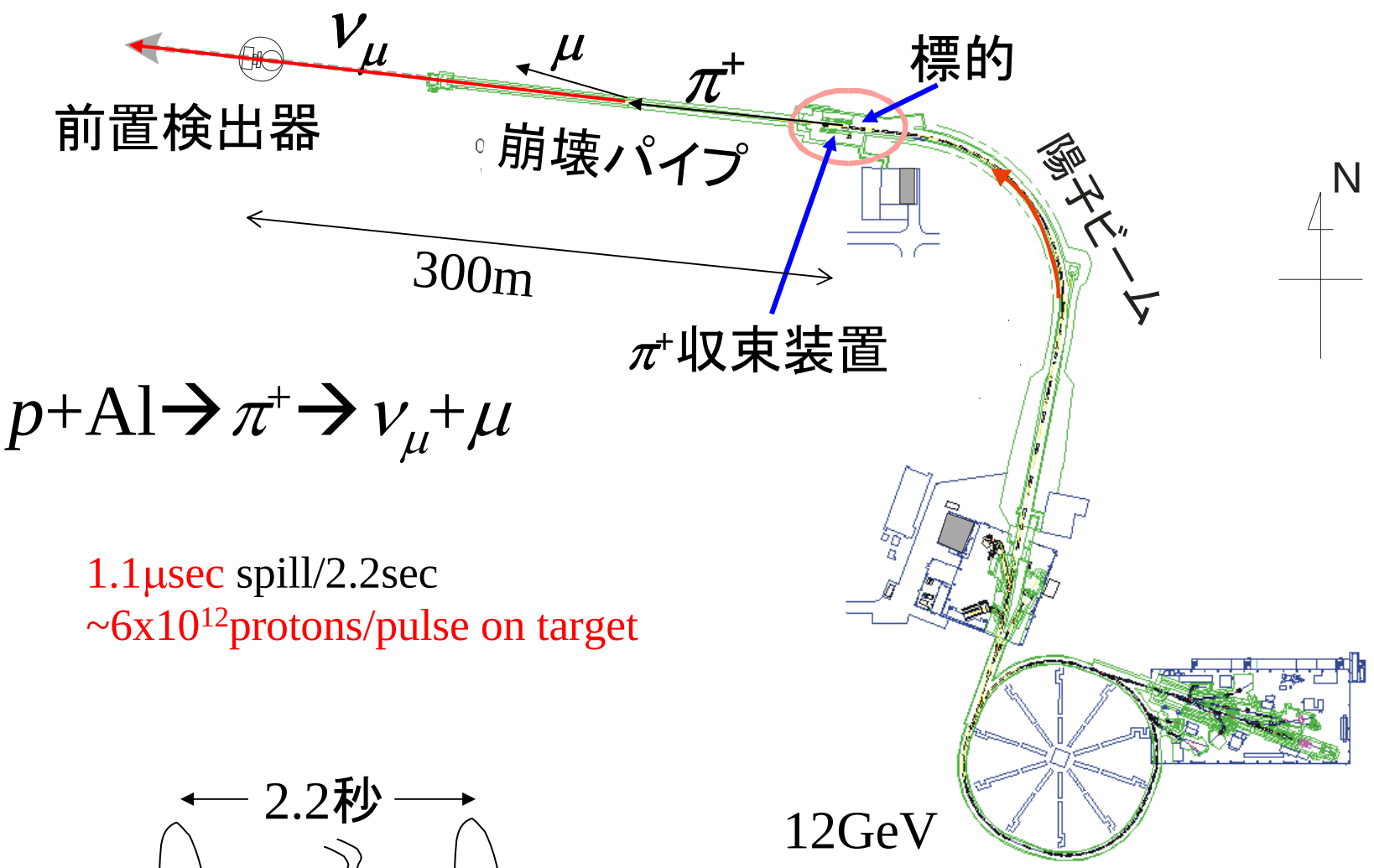
  Super Kamiokande(SK)

  @**250km**
- Sensitive for

  $\Delta m^2 > 2 \times 10^{-3}$ **eV**^{2}
- ν_μ disappearance

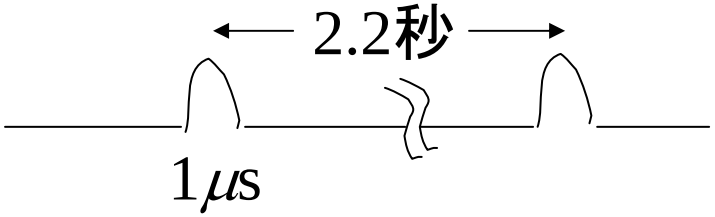
  ν_e appearance

Neutrino facility in KEK

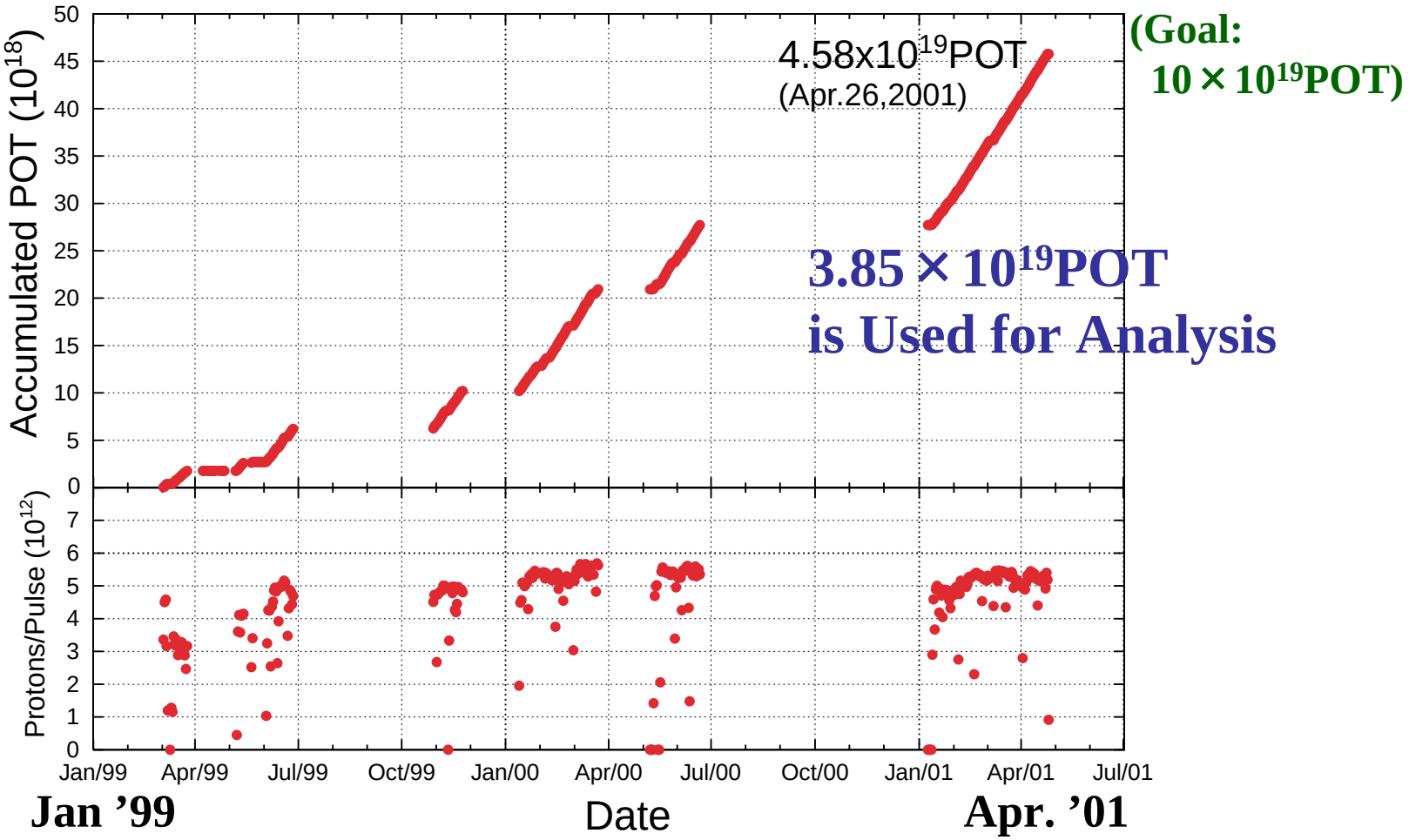


p+Al→π^+→ν_μ+μ

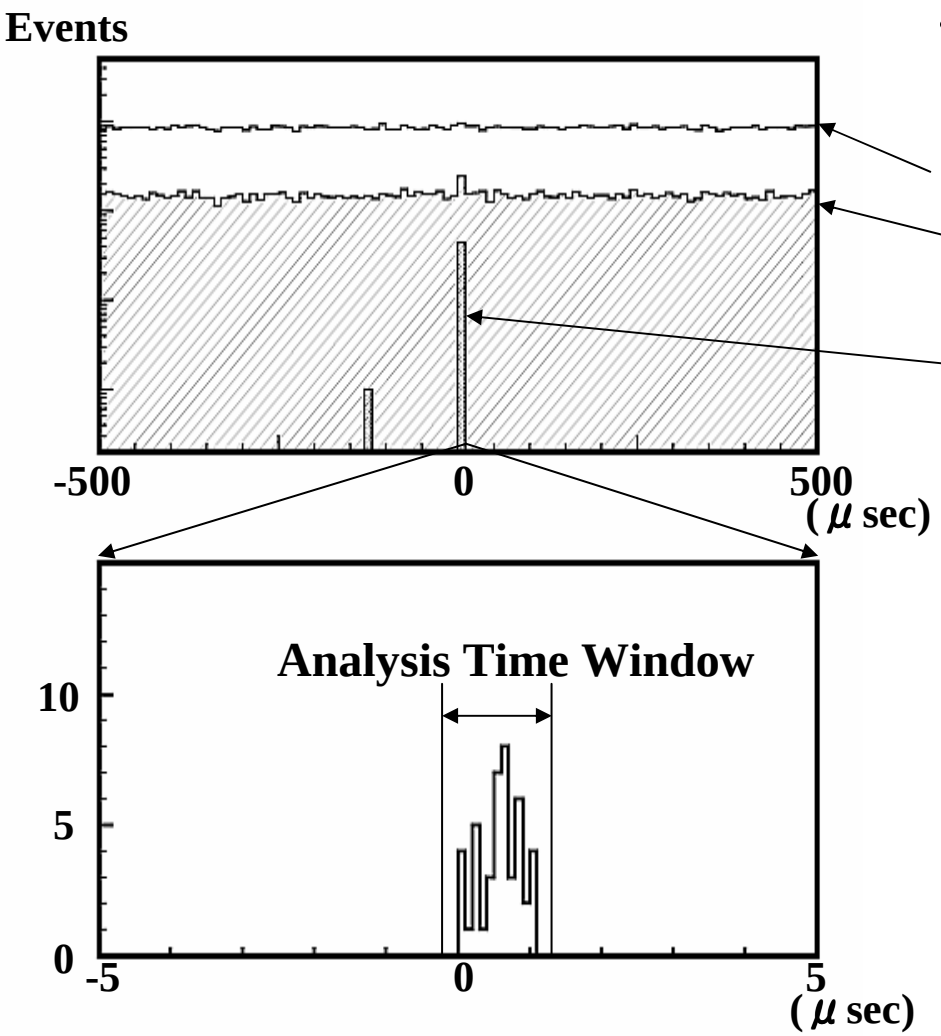
1.1μsec spill/2.2sec
~6x10^{12}protons/pulse on target

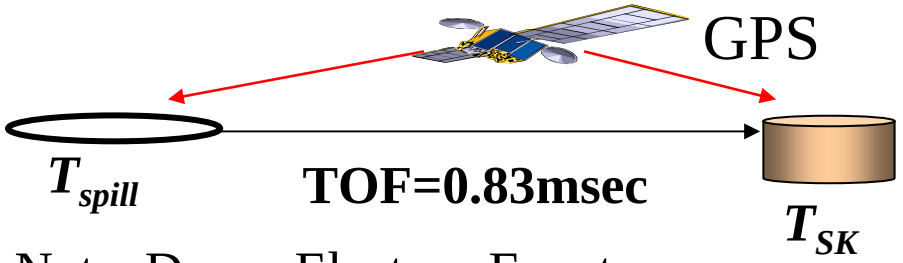


Accumulated Protons on Target at K2K:



Observation at Far Site:





Not a Decay Electron Event

More than 20MeV Deposited Energy

No Activity in Outer Detector
Event Vertex is in Fiducial Volume
More than 30MeV Deposited Energy

44 Events

in

$-0.2<T_{SK}-T_{spill}-\mathrm{TOF}<1.3\mu\mathrm{sec}$

Analysis Time Window

(B.G. $<10^{-3}$ in 1.5μs Window)

Expected No. of ν_μ Interactions at Far Site

	Near (1kt)	Far (SK)
Fiducial Mass	25 tons	22500 tons
Energy Threshold	>100MeV*	>30MeV*
Efficiency	74%	79%

(* Deposited Energy)

$$N_{far}^{exp} = 63.9^{+6.1}_{-6.6}$$

Dominant Systematic Uncertainty

Far to Near Extrapolation	7%
1kt (Mainly due to Fiducial Volume)	5%
SK (Mainly due to Fiducial Volume)	3%
Statistical Uncertainty	<1%

c.f.

MRD $N_{far}^{exp} = 69.8^{+10.2}_{-11.2}$

SciFi $N_{far}^{exp} = 64.6^{+7.7}_{-8.7}$

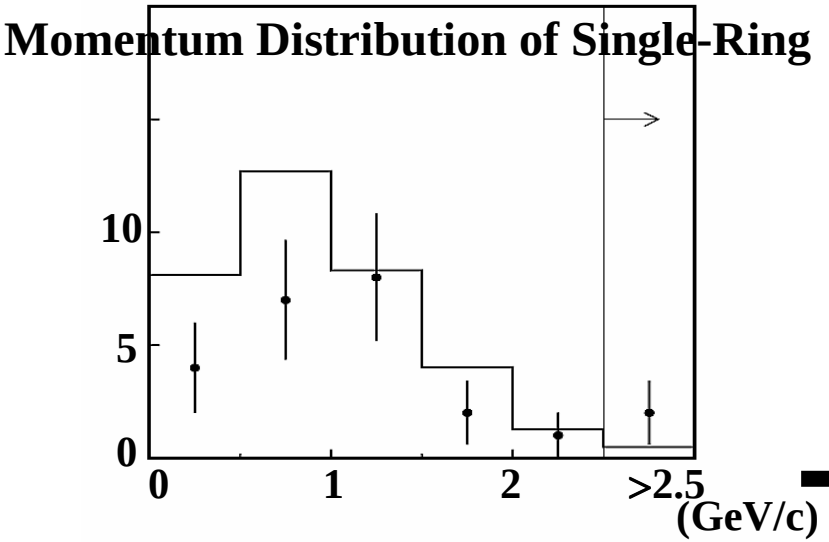
Work in Progress

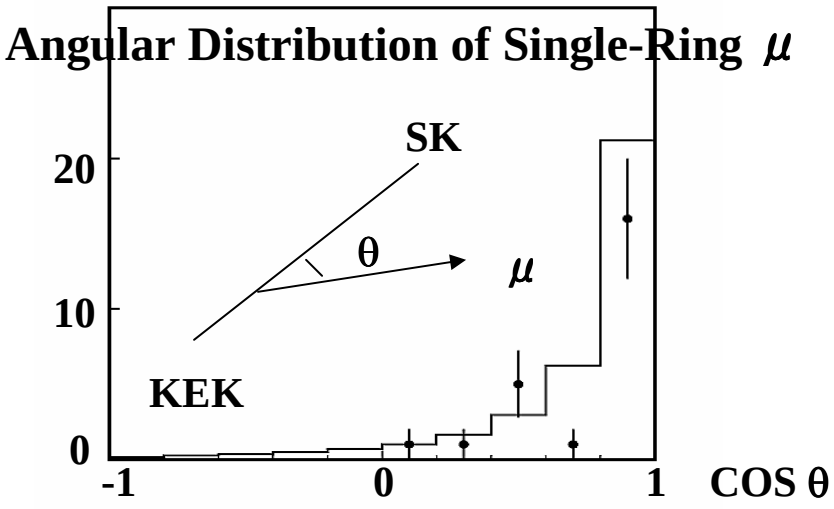
Observed Neutrino Spectrum at Far Site:

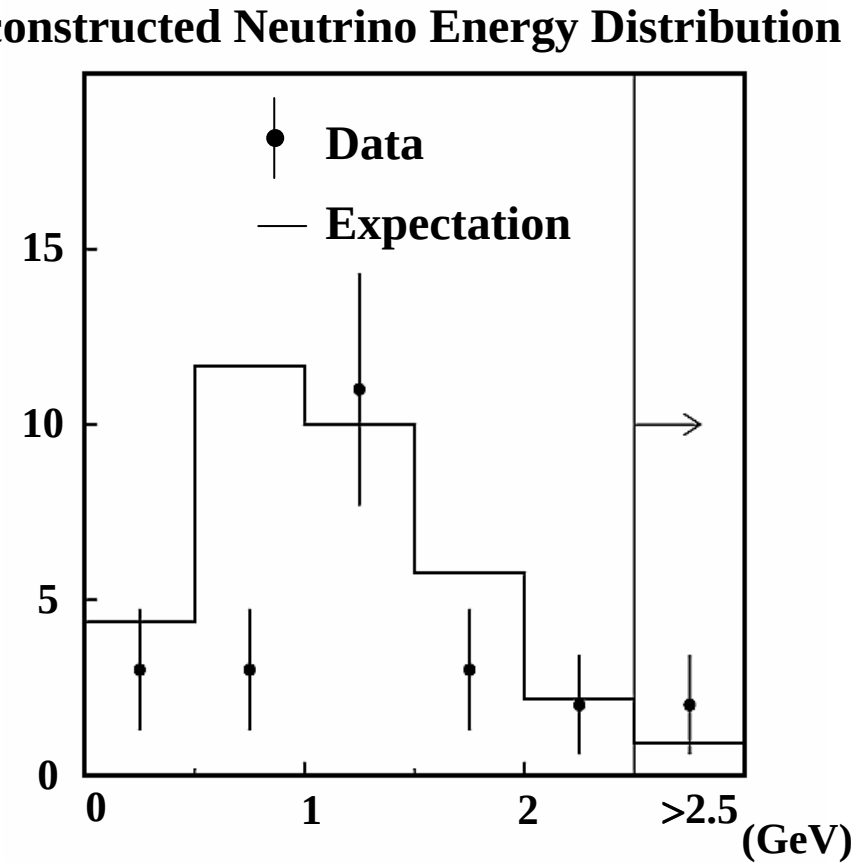
Statistical Uncertainty Only !!

Evaluation of Systematic Uncertainty

inc. Bin by Bin Correlation is Necessary !!

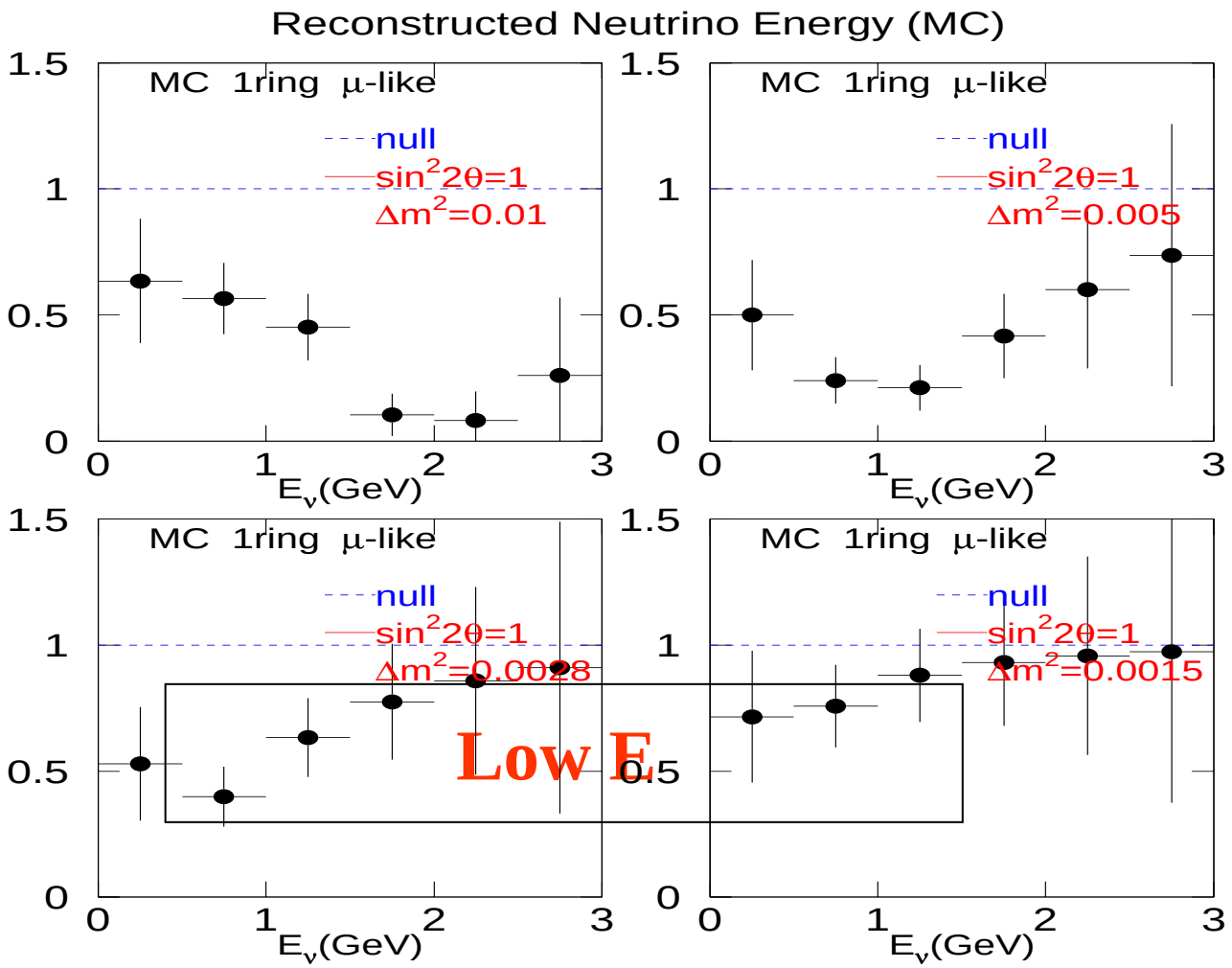






Oscillation Effects

Good sensitivity with low energy neutrinos for small Δm^2



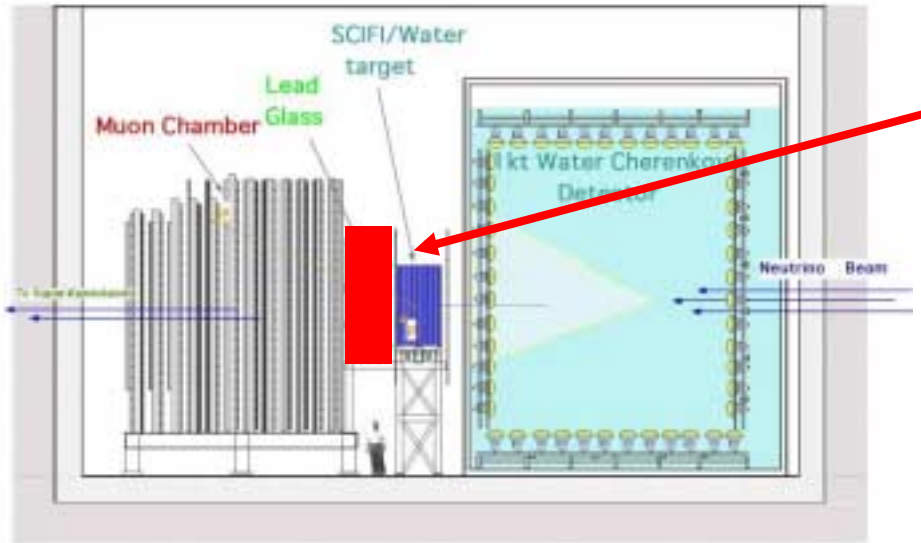
K2K Upgrade

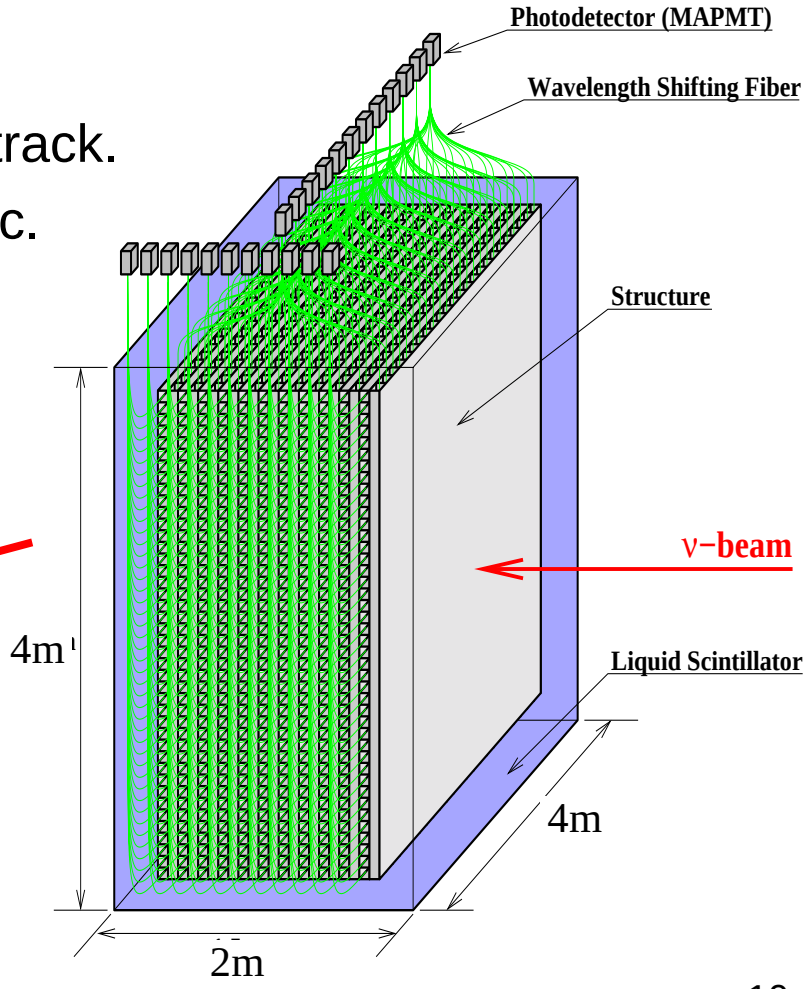
•Brand new near detector to study neutrino interactions below 1 GeV

$L=250km,\ \Delta m^2 = 3 \times 10^{-3}$ $E\nu \sim 0.6GeV$

Scintillator Tracker

- High efficiency for a short (~5cm) track.
- Detect a proton down to 400 MeV/c.
- PID (p/π) by dE/dx.
- Fine segments ($2 \times 2 \times 300 cm^3$).





What's next?

- Definite confirmation of $\nu_\mu \rightarrow \nu_{x(\tau)}$ osc. w/ acc-based exp.
  - K2K(1999~)
  - MINOS(2005~) FNAL-Soudan(730km), ν_μ disapp.
  - OPERA/ICARUS(2005~) CERN-GranSasso, ν_τ app.

- Search for $\nu_\mu \rightarrow \nu_e$ osc.
  - (K2K), JHF-SK
    - → test 3 flavor mixing
- Precision measurement of osc. param.
  - JHF-SK, MINOS
    - → constrain new/exotic physics
- Search for CP violation
  - JHF-SK/HyperK

High stat., high precision
"2nd generation neutrino oscillation experiment"

Neutrino Oscillation

Neutrino Mixing

$$|\nu_l\rangle = \Sigma U_{li} |\nu_i\rangle$$

Weak eigenstates — Mass eigenstates

Maki-Nakagawa-Sakata Matrix

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

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-i\delta} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix}$$

Solar — Atm, LBL — LBL, Reactor

Oscillation Probability

When $\Delta m^2_{12} << \Delta m^2_{23} \approx \Delta m^2_{13} \equiv \Delta m^2_{atm}$, $E_\nu \approx \Delta m^2_{atm} \cdot L$

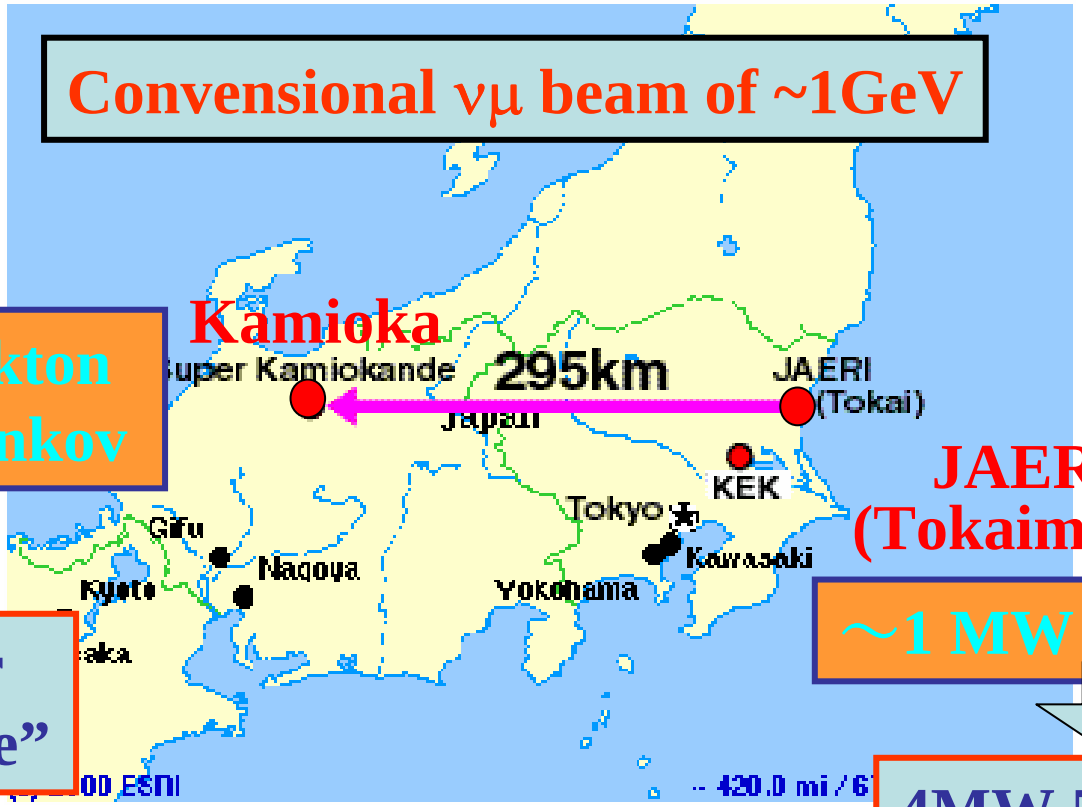
$$P_{\mu\to x} \approx 1 - \underbrace{\cos^4\theta_{13}}_{\sim 1} \cdot \underbrace{\sin^2 2\theta_{23}}_{\sim 1} \cdot \sin^2\left(1.27\Delta m^2_{atm}/E_\nu\right)$$

Same

$$P_{\mu\to e} \approx \underbrace{\sin^2\theta_{23} \cdot \sin^2 2\theta_{13}}_{\sim 0.5} \cdot \sin^2\left(1.27\Delta m^2_{atm}/E_\nu\right)$$

$\sin^2 2\theta_{\mu e}$

JHF-SK ν project Overview



Super-K: 50 kton Water Cherenkov

~Mt "Hyper Kamiokande"

JAERI (Tokaimura)

~1 MW 50 GeV PS

4MW 50GeV PS

First Phase

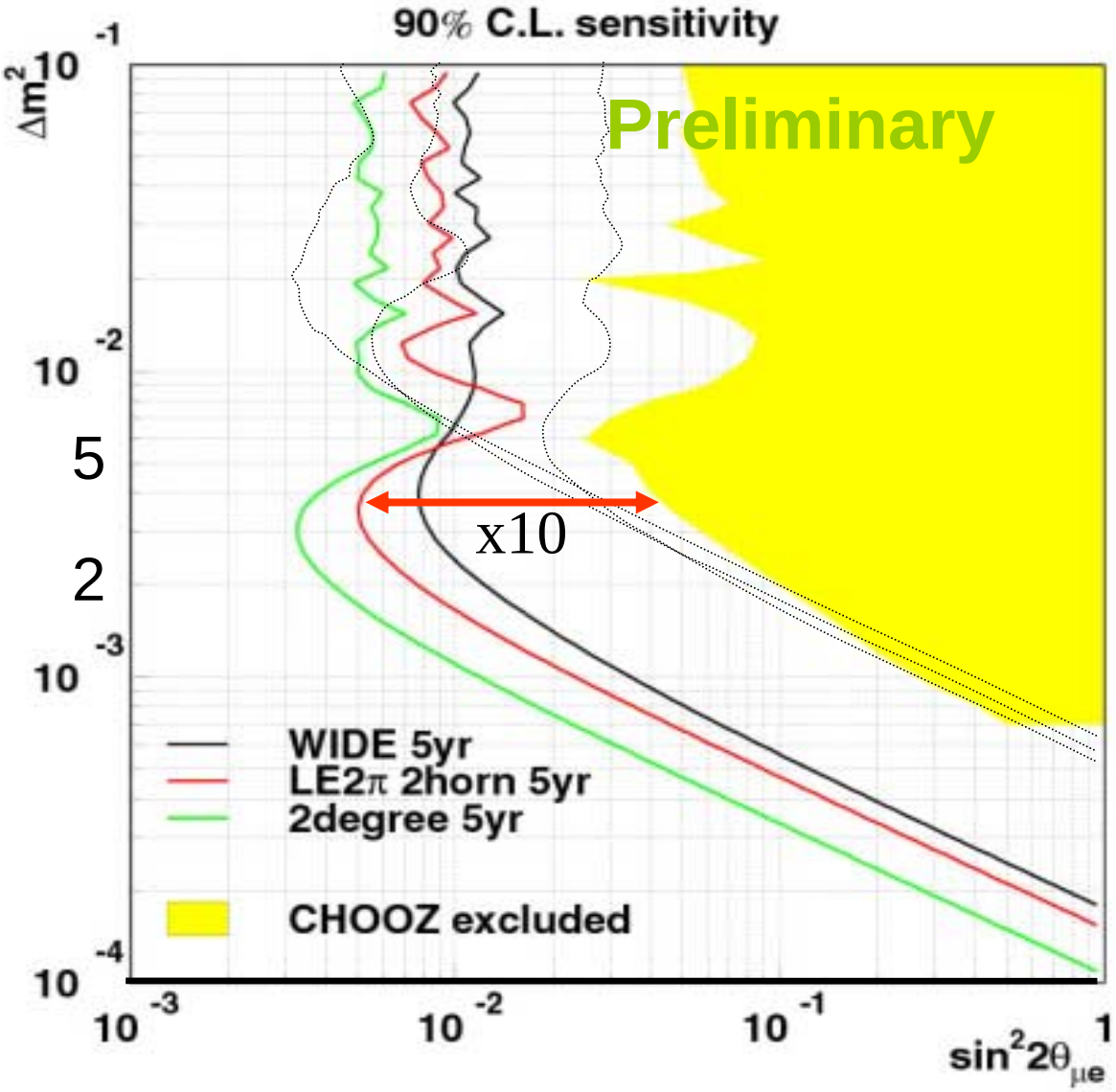
- $\nu_\mu \rightarrow \nu_x$ disappearance
- $\nu_\mu \rightarrow \nu_e$ appearance
- NC measurement

Second Phase

- CPV
- proton decay

(cf. K2K: ~5kW)

Sensitivity on $\nu_\mu \rightarrow \nu_e$ appearance

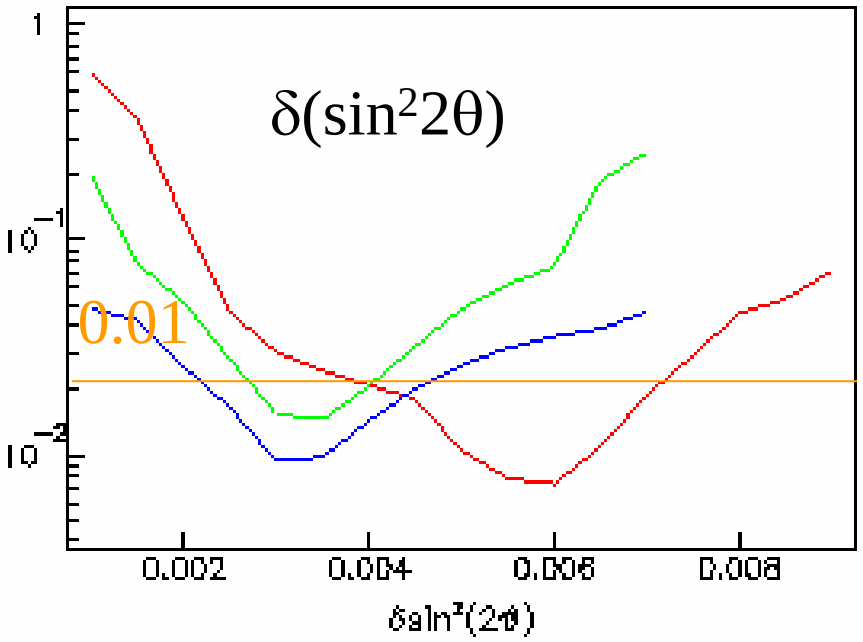


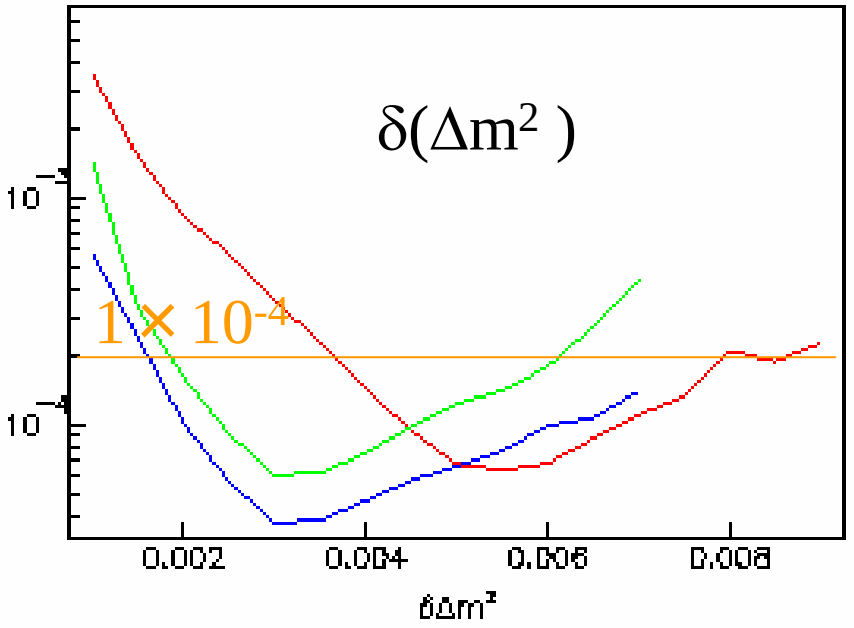
Dashed lines: MINOS Ph2le, Ph2me, Ph2he from right
(A.Para, hep-ph/0005012)

Precision measurement of osc. parameters

(ν_μ disappearance)

NBB-3GeVπ, OAB-2degree, NBB-1.5GeVπ





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

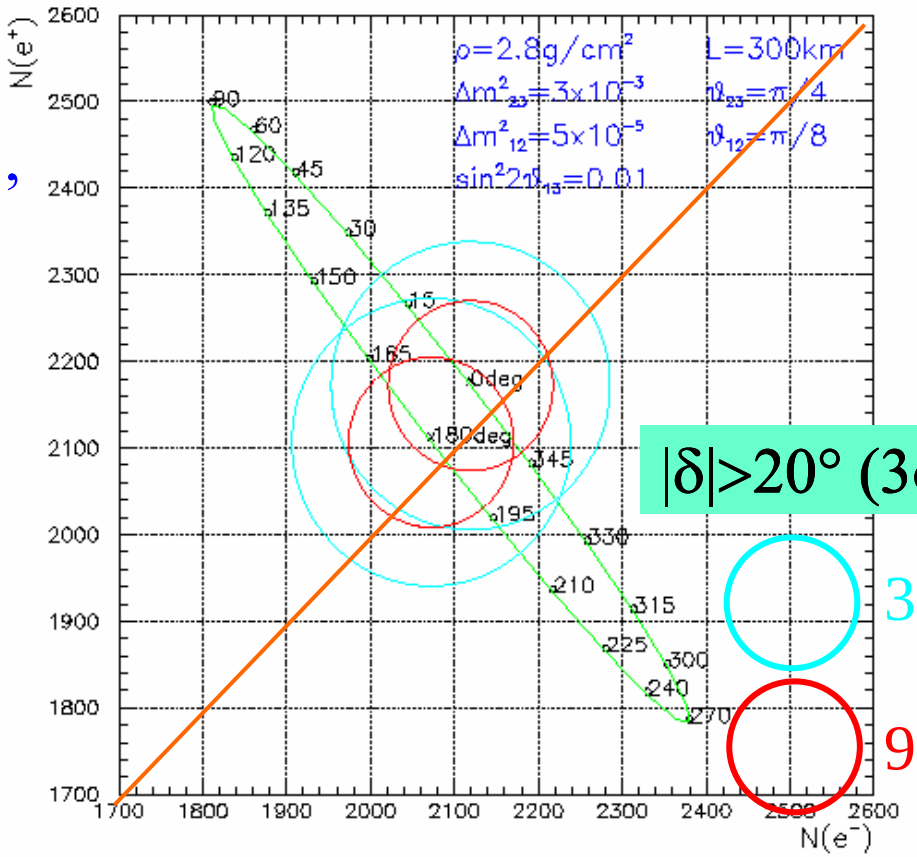
$\delta(\Delta m^2) \sim < 1 \times 10^{-4}$ in 5 years

CP Violation Study(2nd phase)

- Compare $\nu_\mu \rightarrow \nu_e$ (2years) with $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ (6years)

$N(e^+)$

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



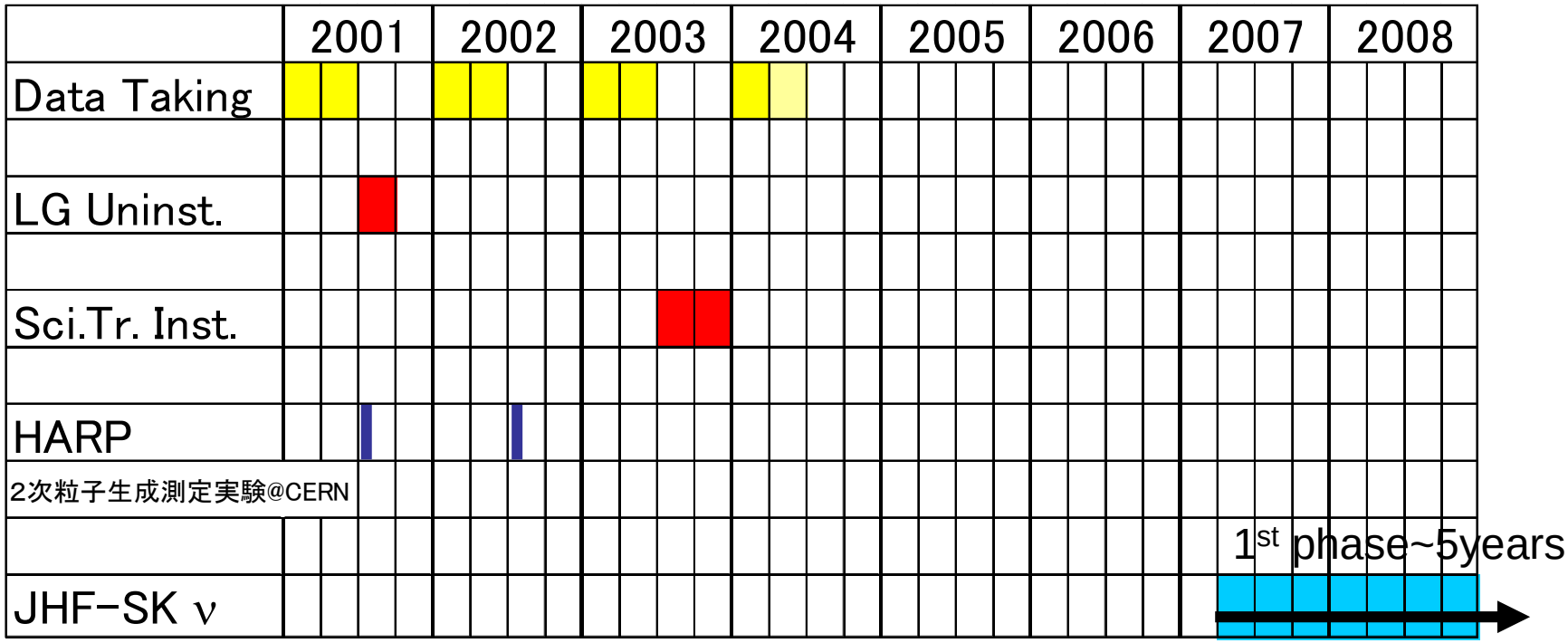
|δ|>20° (3σ **discovery**)

3σ discovery

90% C.L.

$N(e^-)$

スケジュール


2001
2002
2003
2004
2005
2006
2007
2008
Data Taking
LG Uninst.
Sci.Tr. Inst.
HARP
2次粒子生成測定実験@CERN
JHF-SK ν
1st phase~5years

Summary

- 3.85×10^{19}POT accumulated
- 44 event observed / $64.9 \pm^{6.1}_{6.6}$ exp'ed
- Significance of the deficit is >97%
- Near detector will be upgraded to improve precision in low E region (2003)
- Run until 2004 (upto 10^{20}POT)
- JHF-SK/HyperK n project (2007~)

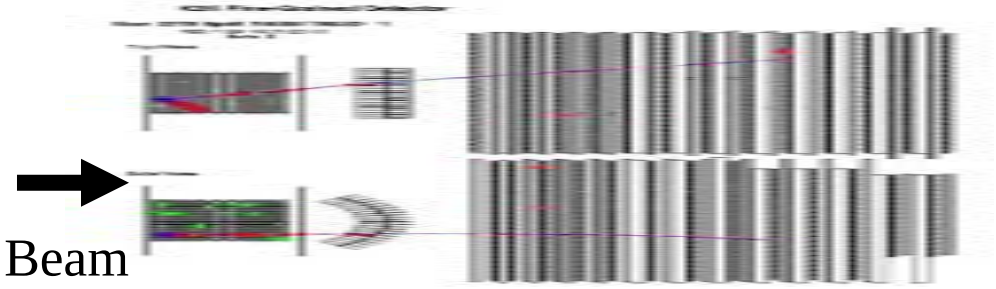
  Goal: Discovery of ν_e appearance

  Precision measurement of osc. parameters

  Discovery of CP violation (2^{nd} phase)

Work in Progress

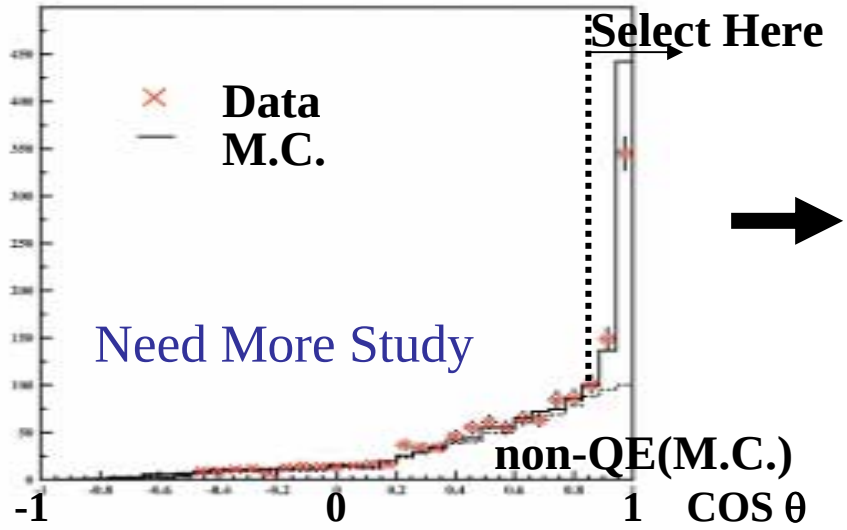
Near Site Neutrino Spectrum Measurement (SciFi+MRD):



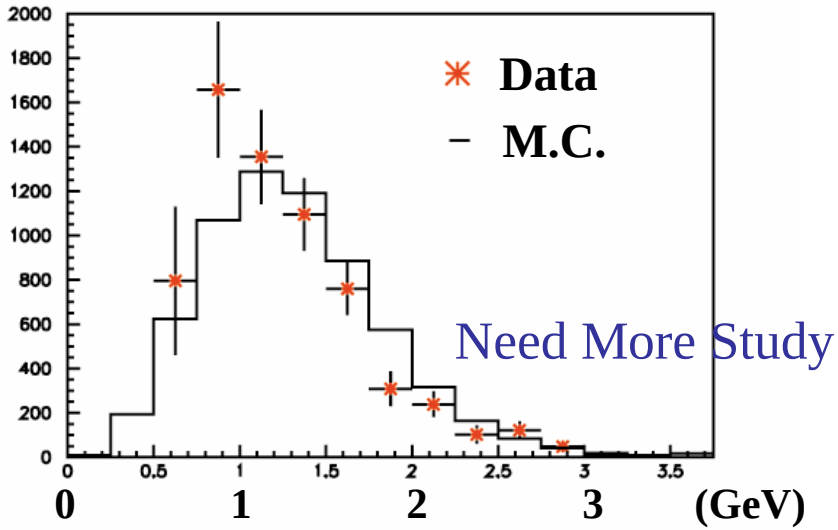
Water Target (+20% Al)
Pos. Resolution ~1mm
Fiducial Mass : 4.9 ton
Event Rate ~ 1/1000pulses

Suitable for Studying
Neutrino Int., e.g. $\sigma_{QE}/\sigma_{non\text{-}QE}$

Expected Angle(QE)－Measured Angle

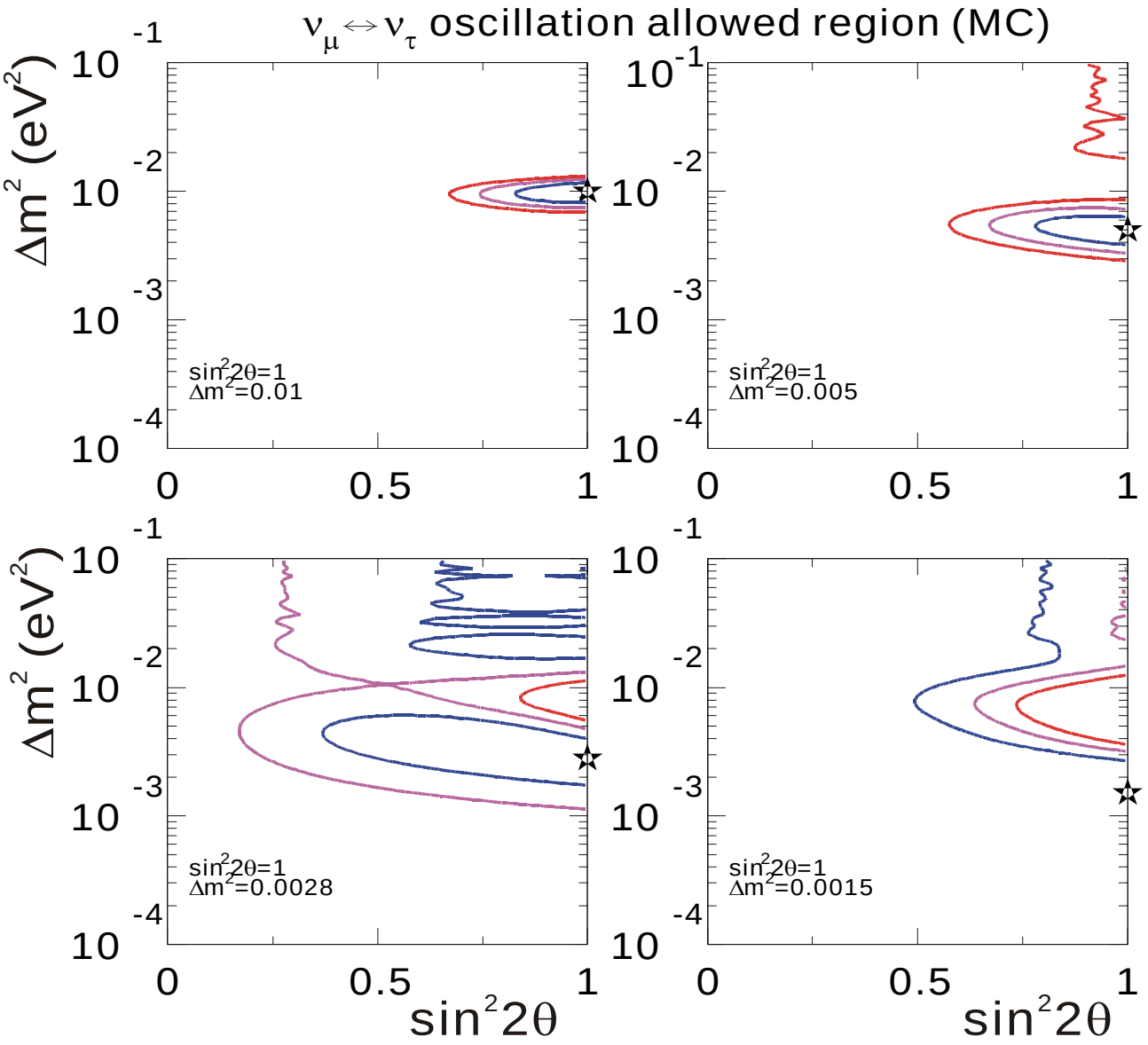


Reconstructed Neutrino Energy Distribution



Expected Allowed Region

10^{20} POT



Current constraints from ν_μ disappearance