Dec.6, 2000
NOON00@Tokyo

Present and future of the Japanese long baseline neutrino oscillation experiment

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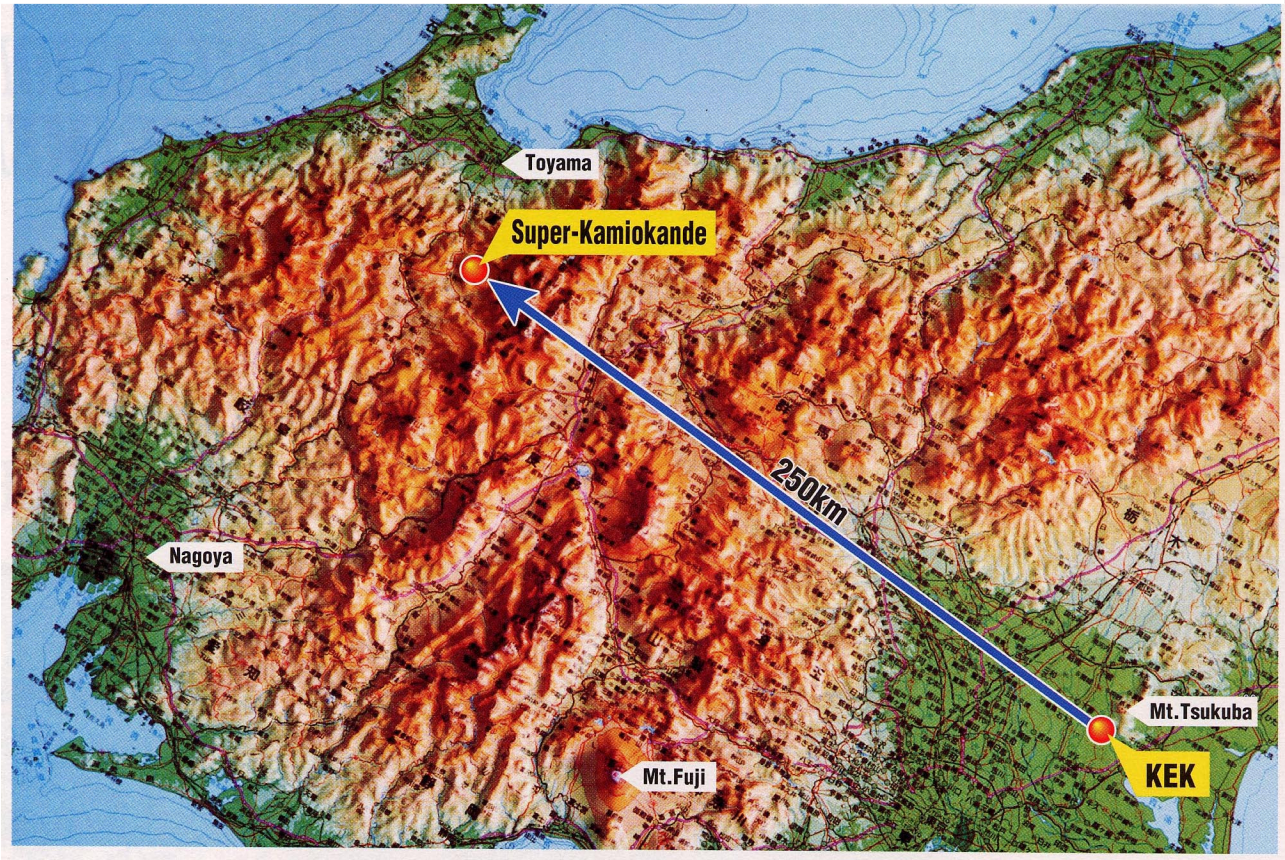
IPNS, KEK

Contents

K2K Overview

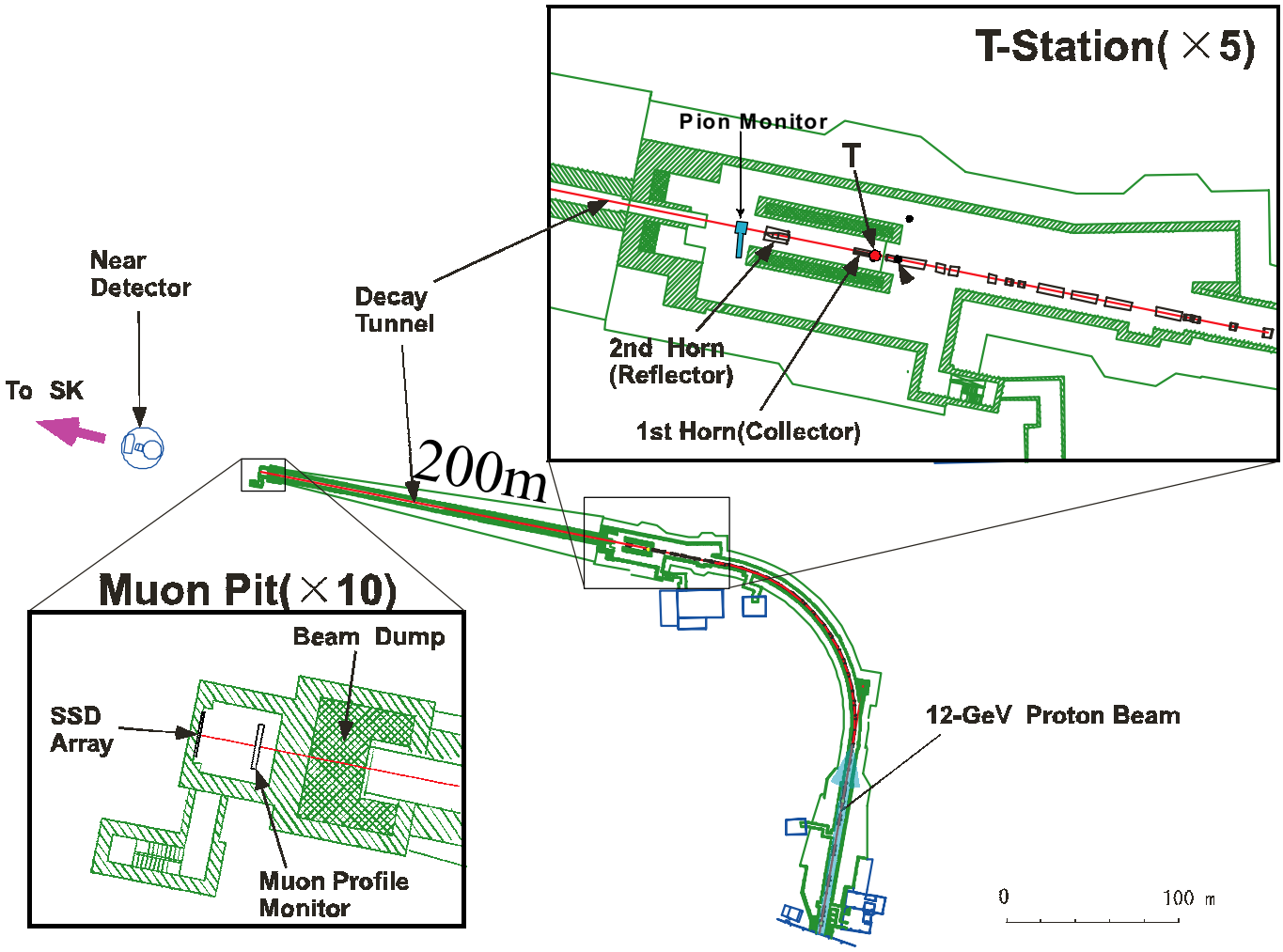


- almost pure ν_μ(99%) beam w/ $<E_\nu>$ ~ **1.3GeV**
- Far detector: Super Kamiokande(SK)@**250km**
- Most sensitive at $\Delta m^2 \sim 7\times10^{-3}$ **eV^2**
- ν_μ disappearance and ν_e appearance

Neutrino Beam Production

$$p\text{+Al} \rightarrow \pi^{+} \rightarrow \mu^{+} + \nu_{\mu}$$

$$\hookrightarrow e^{+} + \nu_{e} + \bar{\nu}_{\mu}\ (1\%)$$

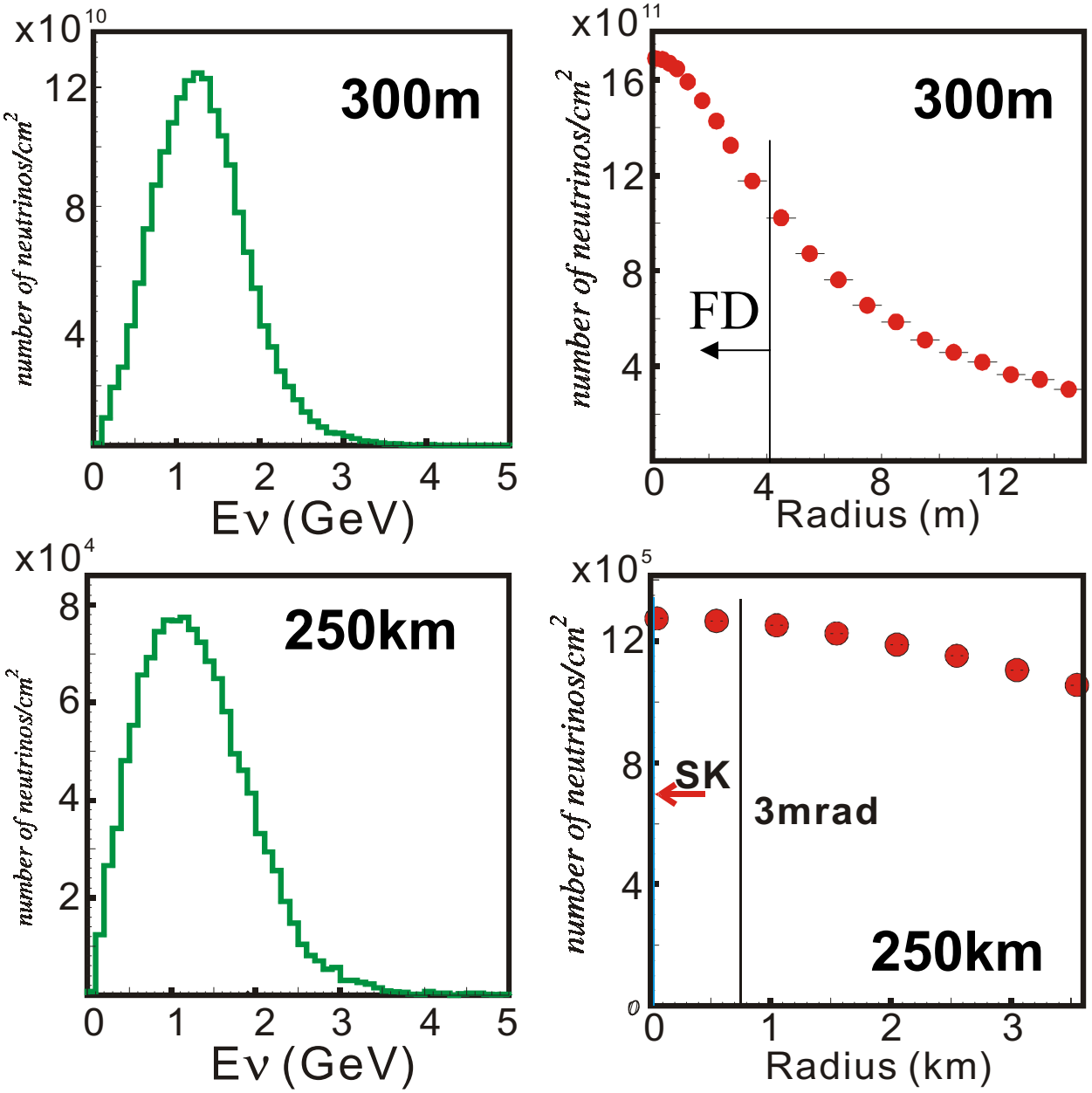


PS: 13GeV/c proton
1.1μsec spill/2.2sec
6×10^{12}protons/spill (design)

Beam line: aligned toward SK using GPS (global positioning system)
GPS< 0.01mrad, civil const<0.1mrad

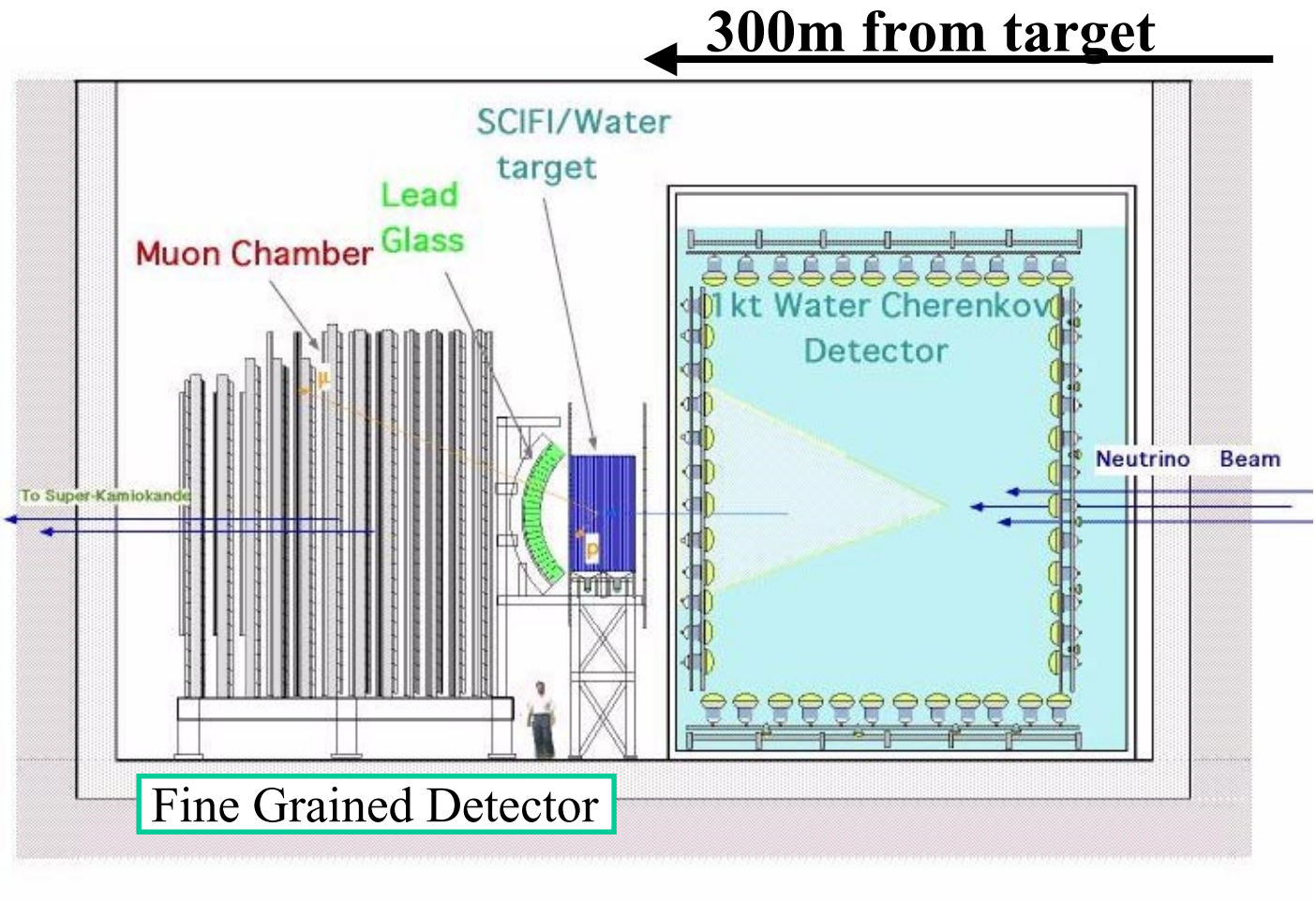
Decay pipe: 200m

Neutrino Spectra and Radial Distributions at 300m/250km (MC)



Almost const flux < 1km(4mr) @ SK
Near/Far spectra differ

Front NeutrinoDetector(FD)



Purpose

1. ν_μ absolute flux
2. ν_μ directrion(profile)
3. ν_e contamination

- 1kt water Cherenkov detector
- Scintillation Fiber Tracker(SFT): SF sheets+water(6cm)
- Electromagnetic calorimeter : lead glass
- Muon chamber (MUC) : drift chamber+iron plates

Strategy

For now,

1. count # of events @ SK

$$N_{SK}^{obs}$$

2. calc. expected # of events @ SK

$$N_{SK}^{exp} = \frac{N_{FD}^{obs}}{\varepsilon_{FD}} \cdot R \cdot \varepsilon_{SK}$$

N_{FD}^{obs} :observed # of events in one of FDs

R: Near/far ratio from MC
(guaranteed by Pi mon)

ε : detection efficiency

3. compare N_{SK}^{obs} and N_{SK}^{exp}

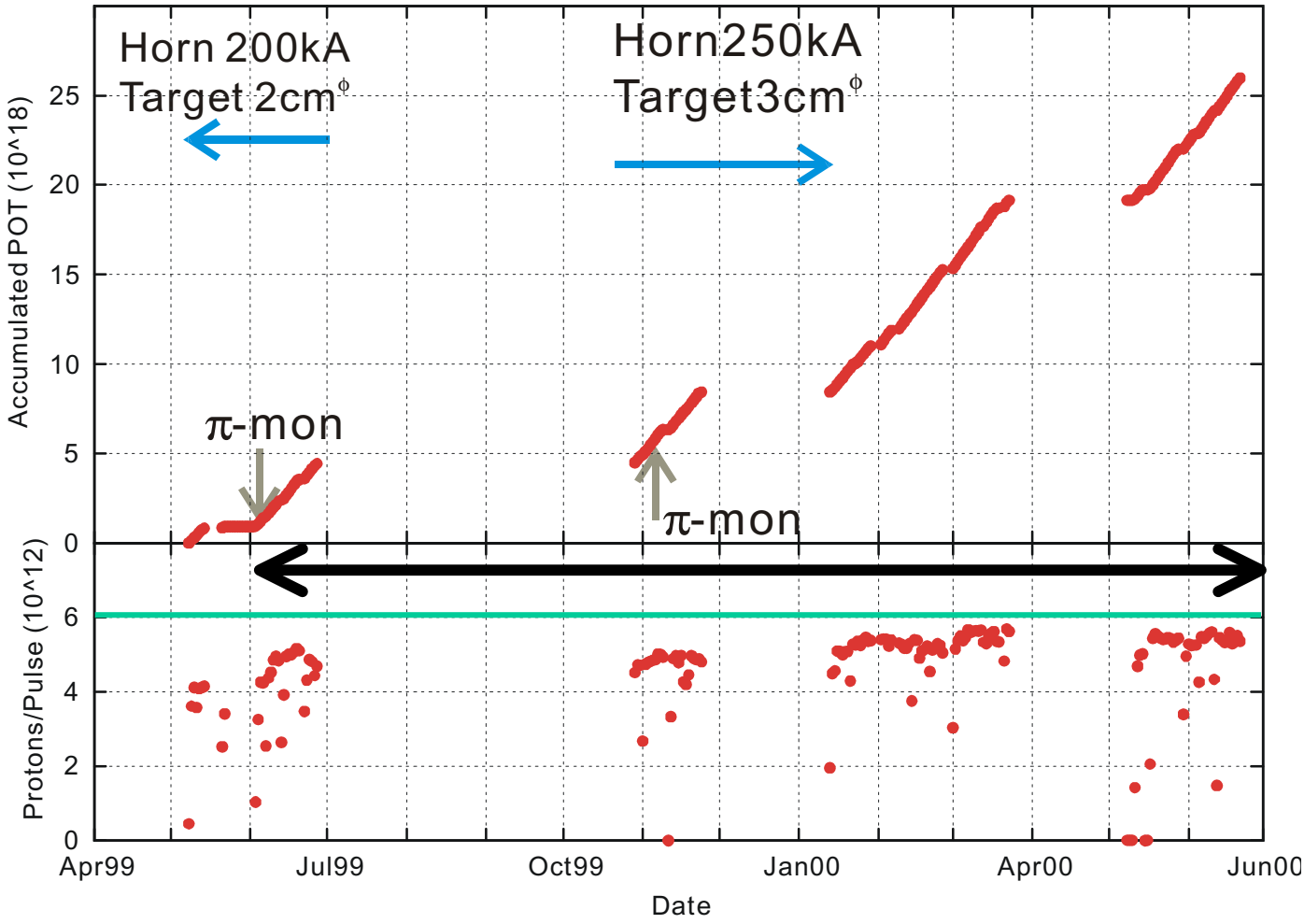
use 1kt events as a reference

check consistency btw. kt/Fe/SFT events

*eventually,…

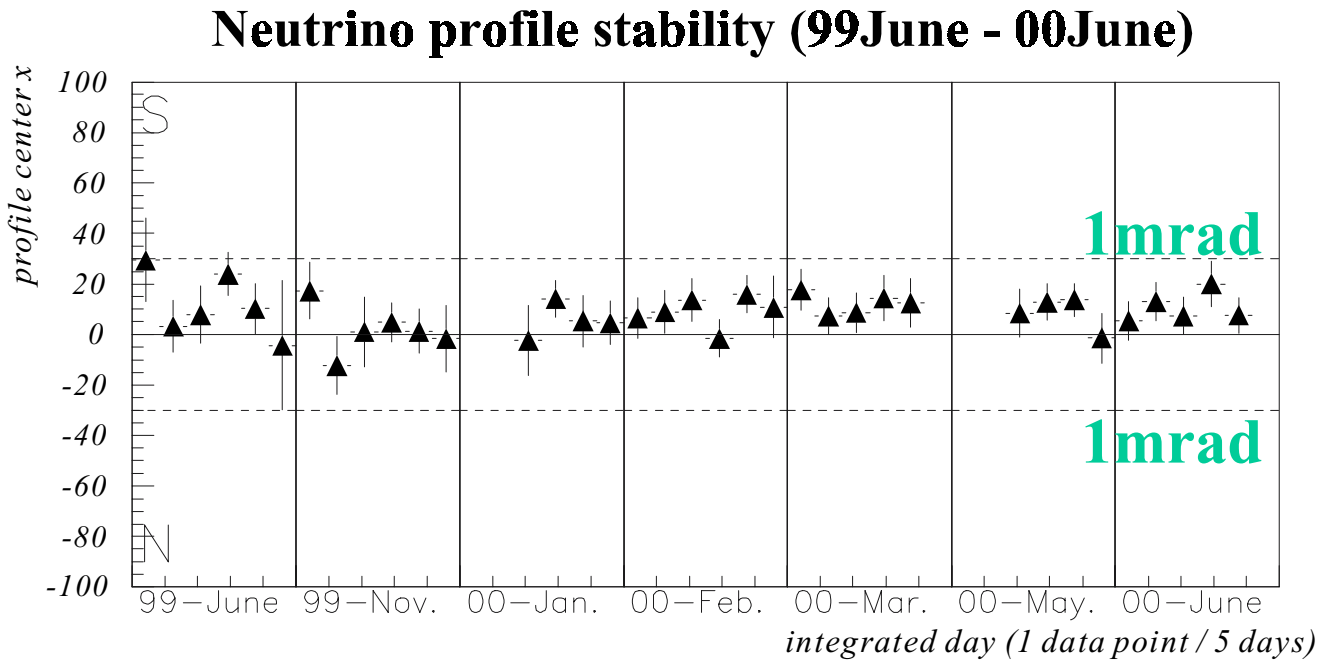
$N_{SK}^{obs}(E_\nu)$ and $N_{SK}^{exp}(E_\nu)$

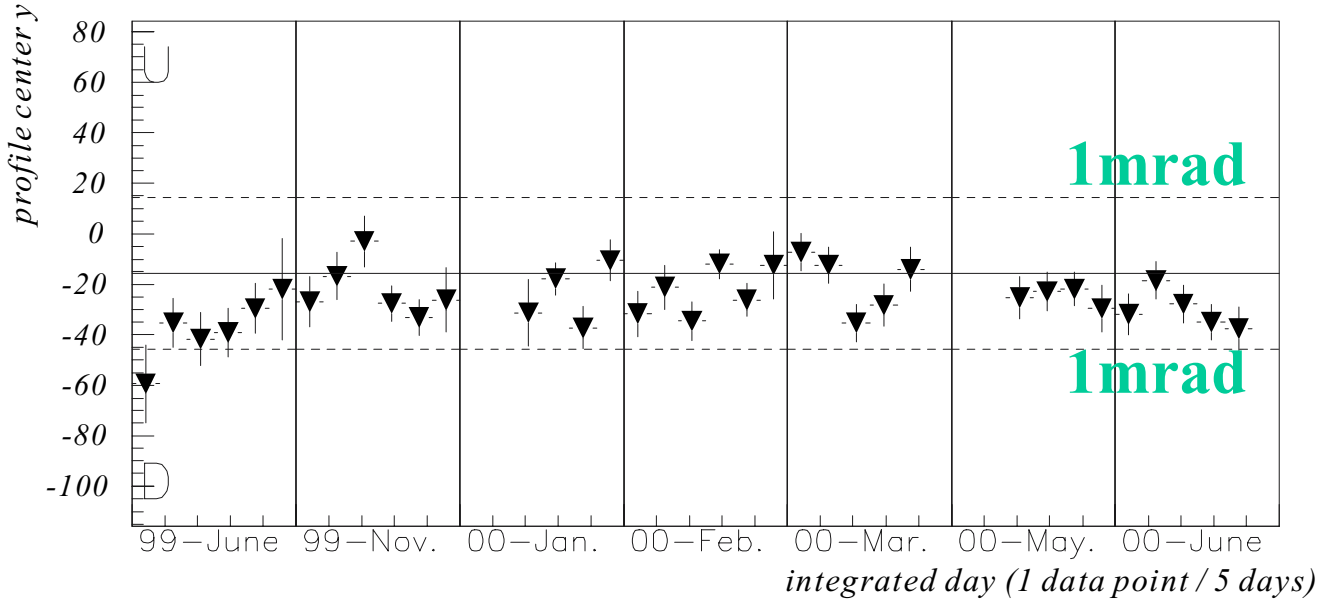
Delivered Beam



- Design Proton Int. 6x10^{12} protons/pulse almost achieved (5.5x10^{12})
- ~2.6x10^{19}POT delivered by the end of Jun. '00
- SK Live = **2.29x10^{19}** POT(Jun99-Jun00)

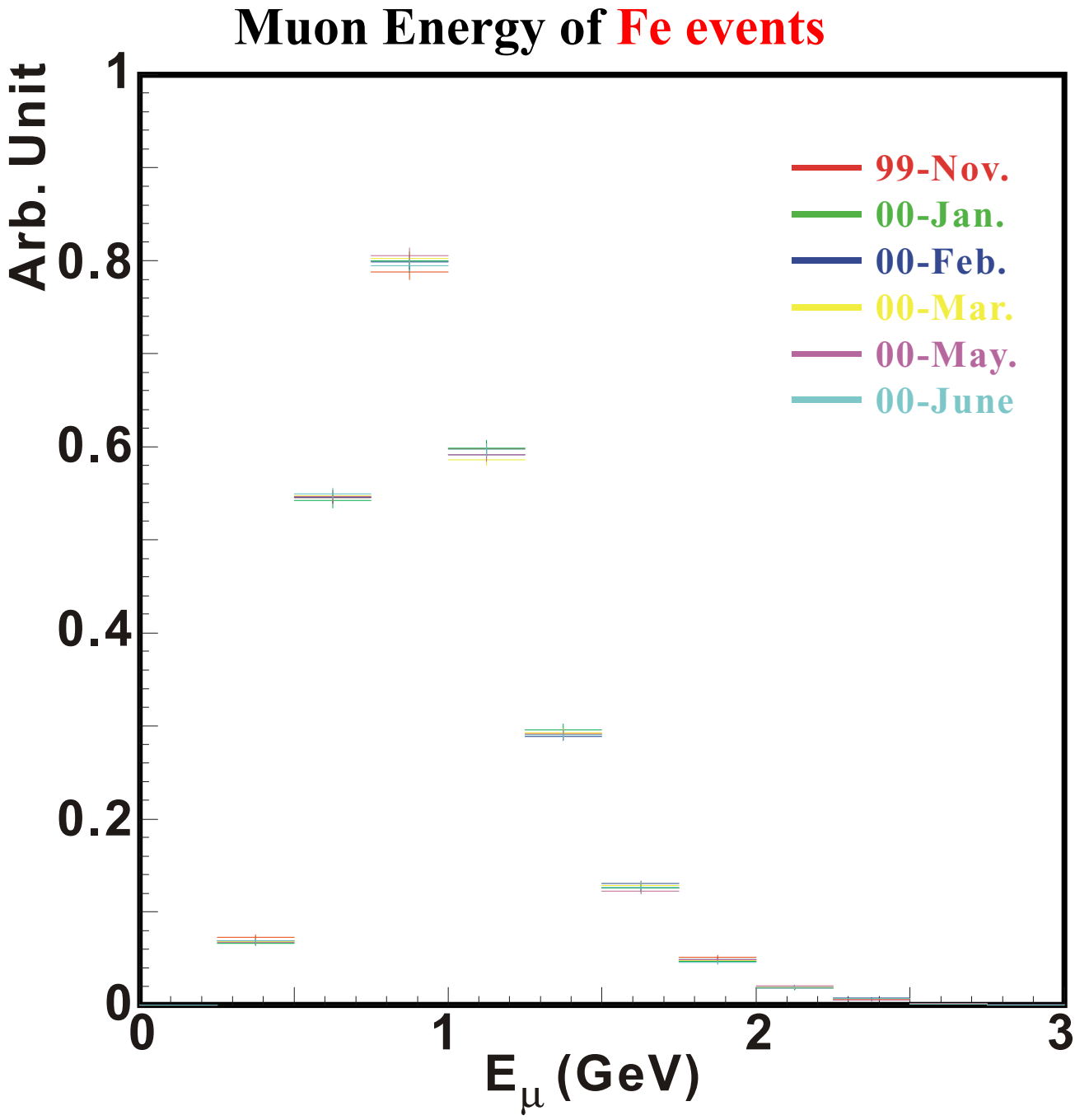
Stability of Profile Center (Fe event)





Stable within ±1mrad.

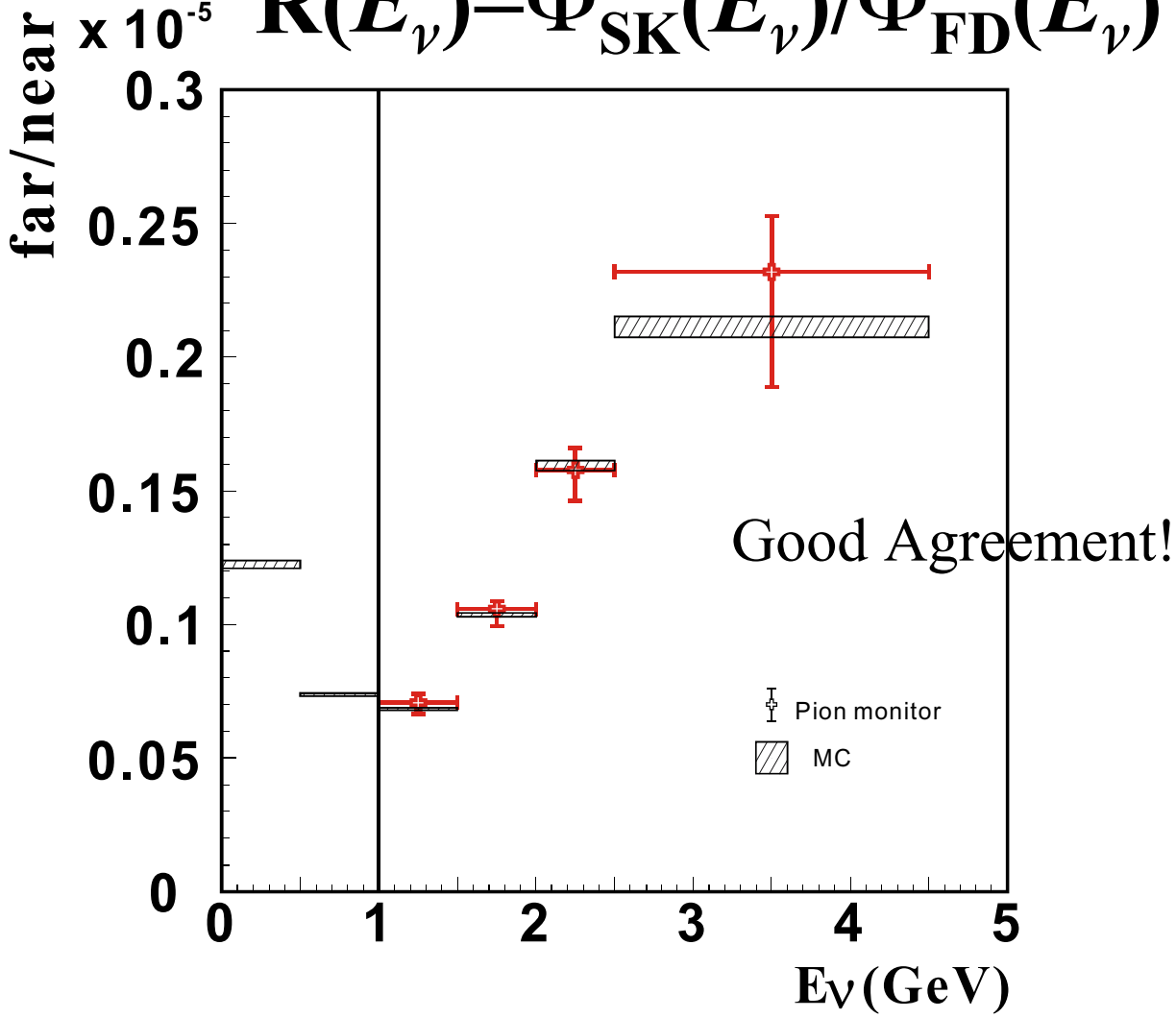
Stability of Spectrum



Stable within stat. error

Flux Ratio from Pion Monitor

$$R(E_\nu)=\Phi_{SK}(E_\nu)/\Phi_{FD}(E_\nu)$$



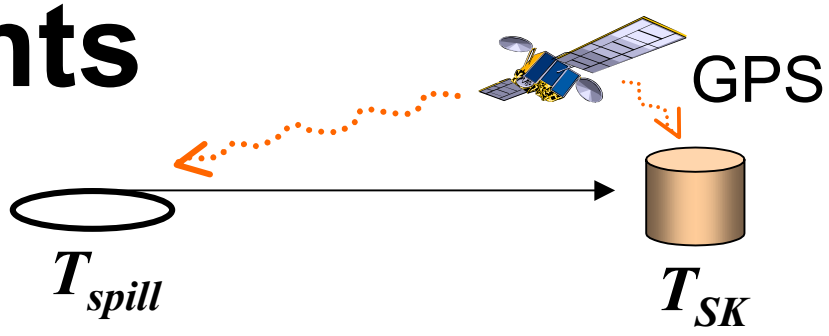
For integrated far/near ratio R in $N_{SK}^{\exp} = \frac{N_{FD}^{\text{obs}}}{\varepsilon_{FD}} \cdot R \cdot \varepsilon_{SK}$

use MC for central value

syst. error $\Delta R = {}^{+6\%}_{-7\%}$ from Pi. mon.

(for 1kt)

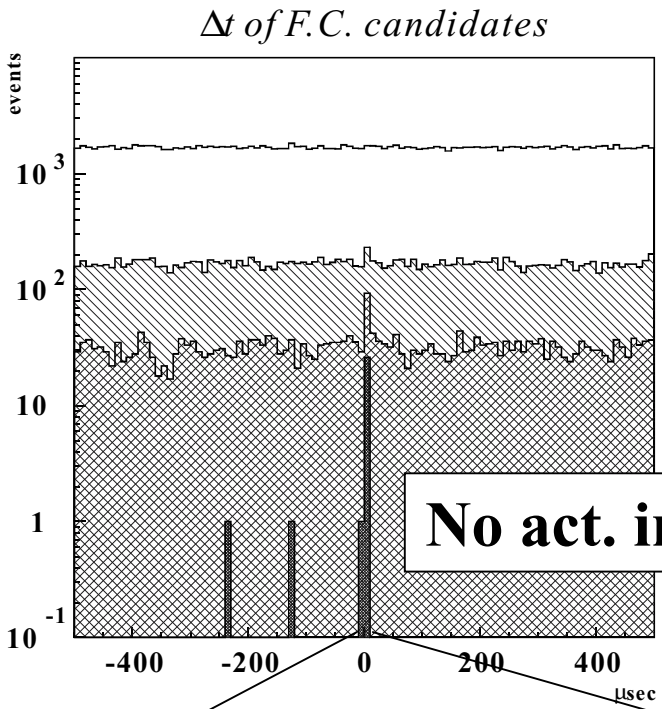
SK Events



$$-0.2 \leq \Delta T \equiv T_{SK} - T_{Spill} - \mathrm{TOF} \leq 1.3\mu\,\mathrm{sec}$$

T_{Spill}, T_{SK}: Abs. time of spill start, SK event measured with GPS

TOF: 0.83ms(Time of flight from KEK to Kamioka)

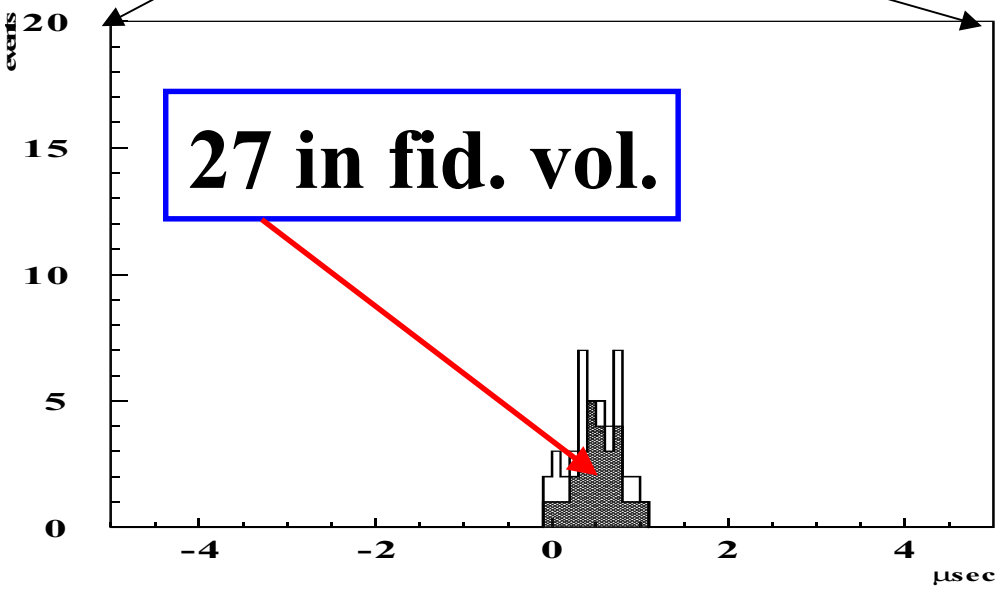


No Decay-e

HE Trig.

Qtot cut

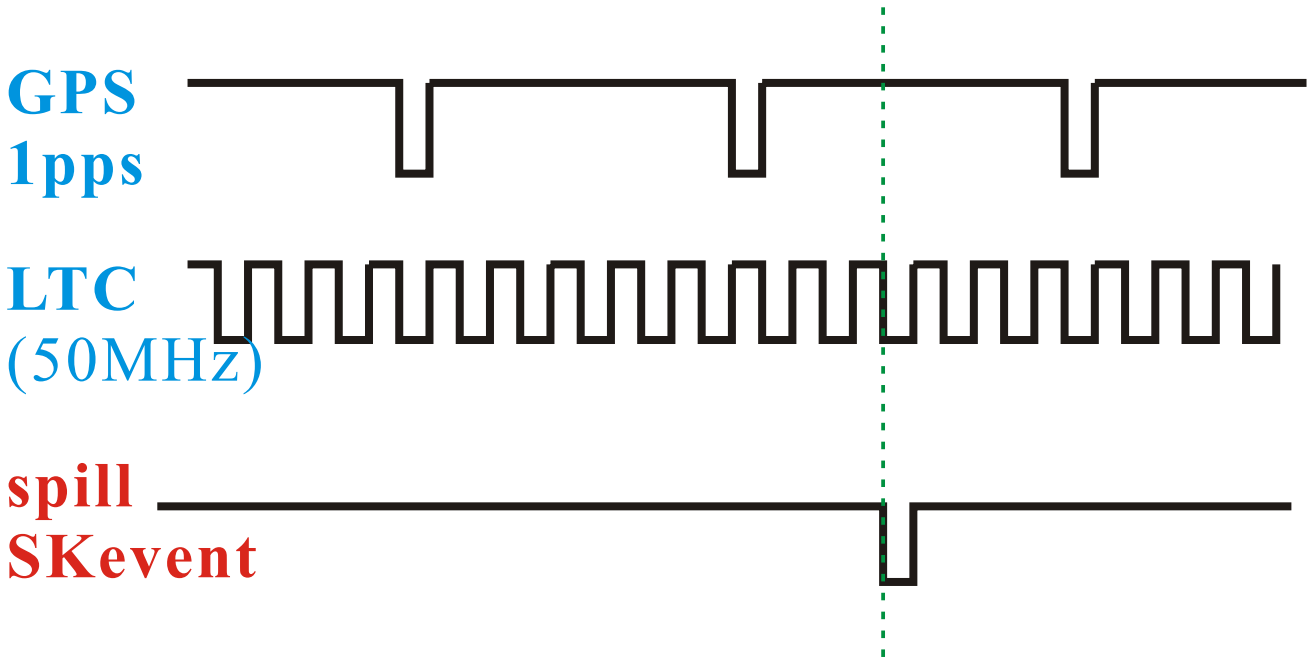
No act. in OD(fully contained)



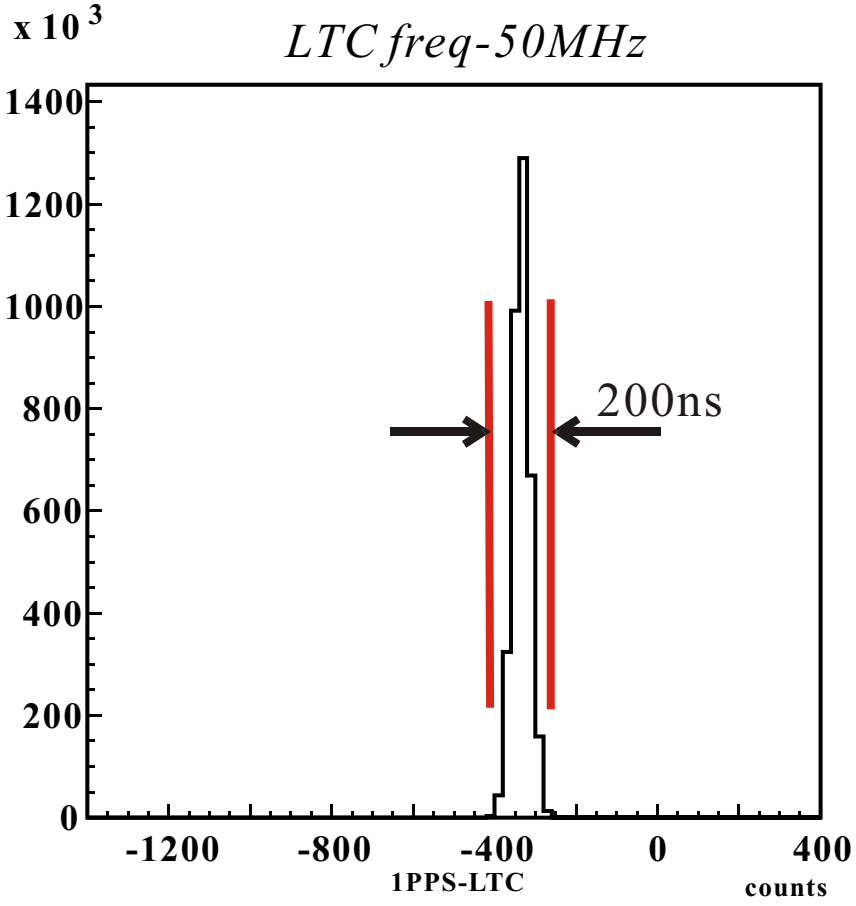
27 in fid. vol.

Exp'ed Atm ν BG $<10^{-3}$ in 1.5μs win.

GPS time stamping



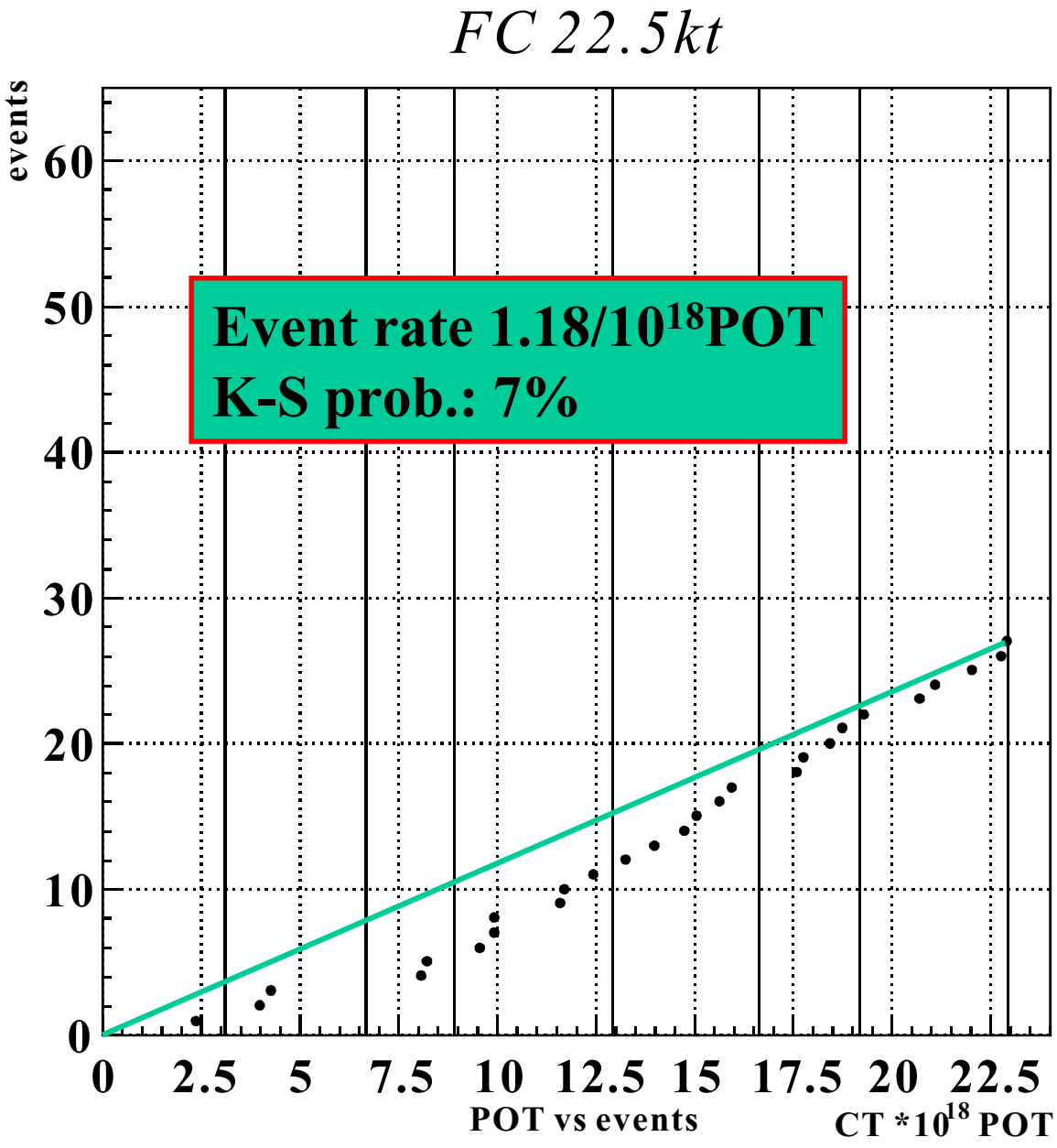
GPS 1pps interpolated with local time clock(LTC



Stable within ±100ns

Event POT Distribution

fully contained, vertex in fiducial volume

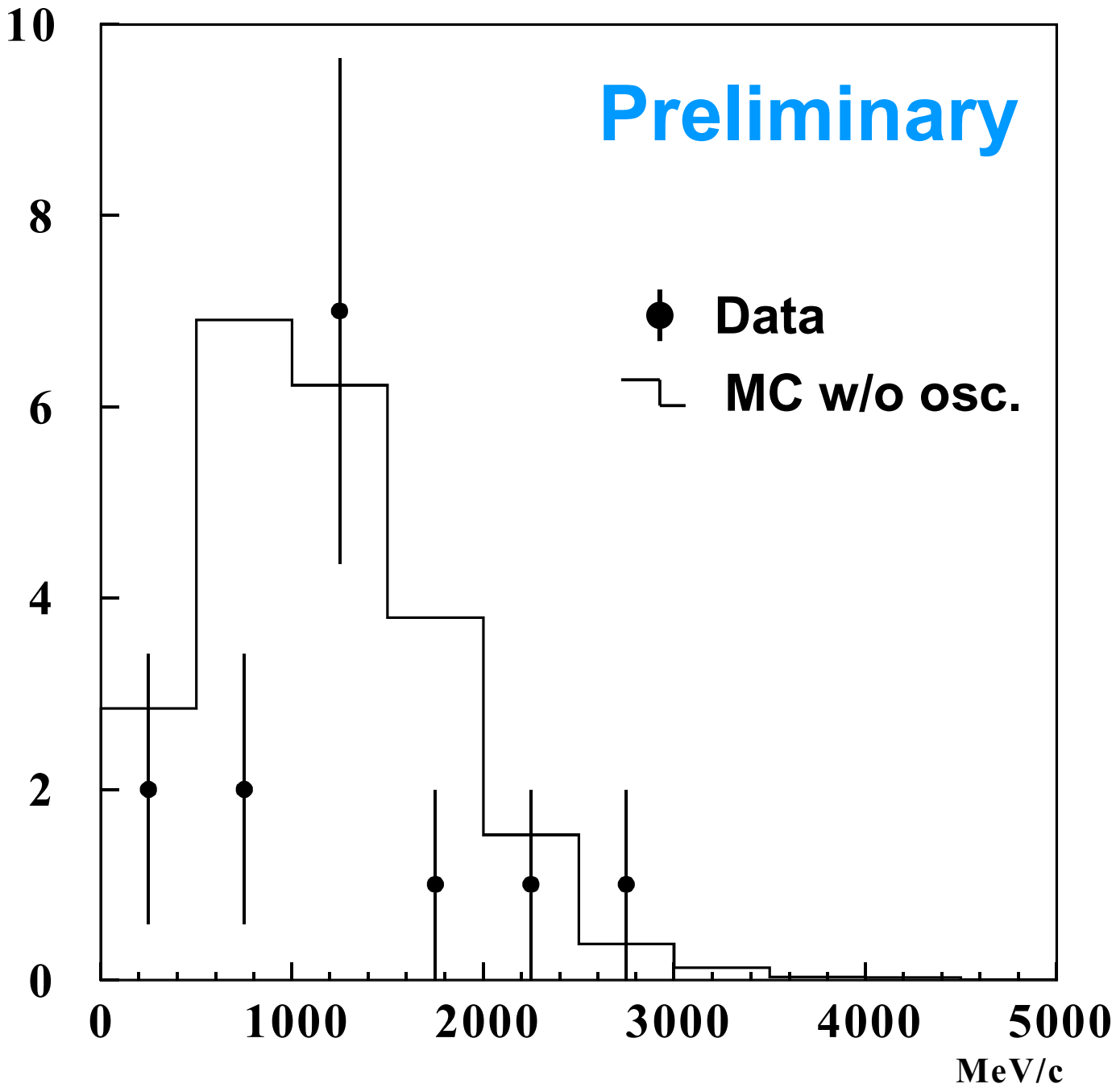


of observed and expected events @ SK

	Obs.	Exp.
FC 22.5kt	27	$40.3\ ^{+4.7}_{-4.6}$
1-ring	15	24.3 ± 3.6
μ-like	14	21.9 ± 3.5
e-like	1	2.4 ± 0.5
multi ring	12	16.0 ± 2.7

Reconstructed E_ν

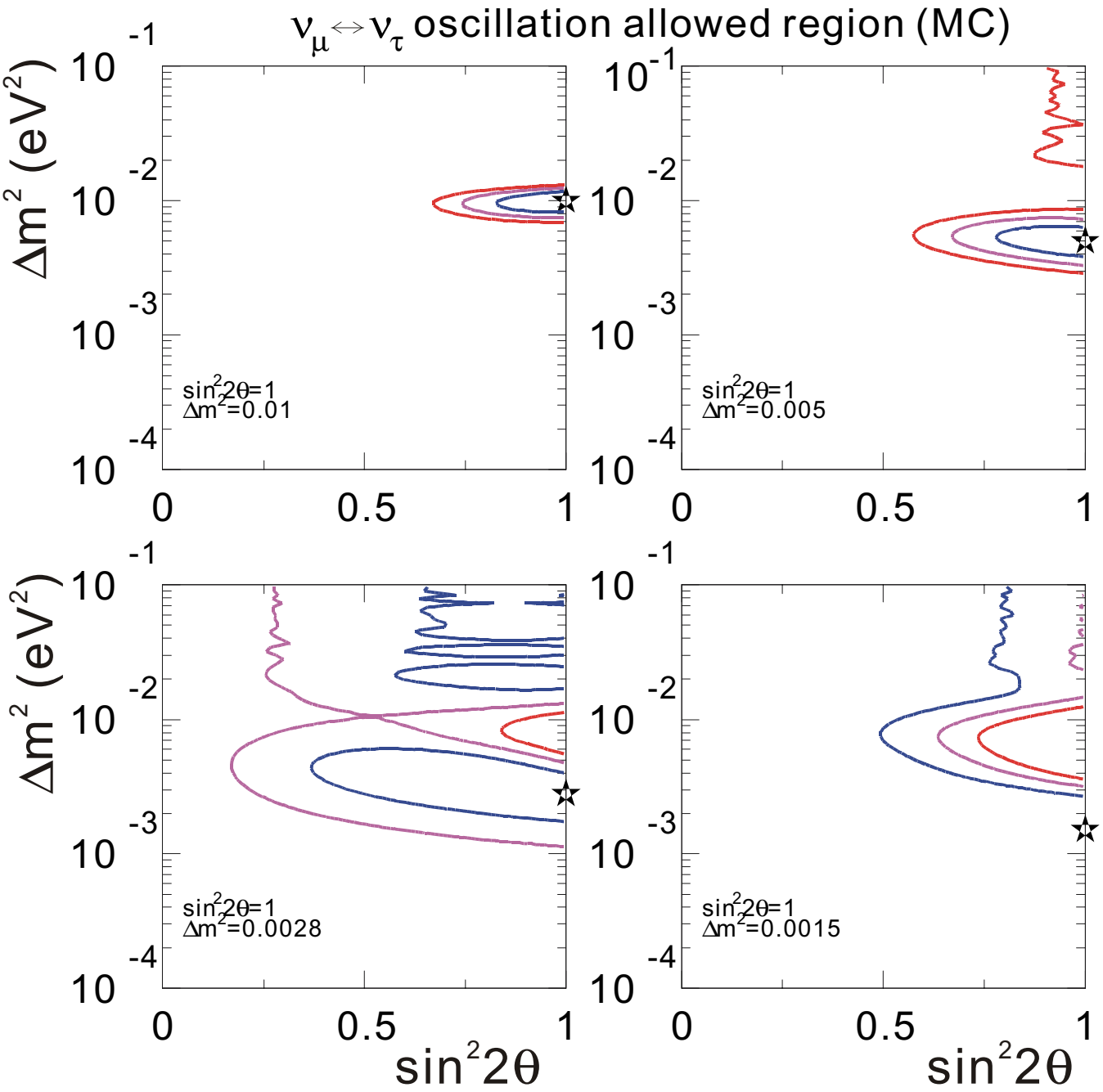
Fully contained 1-ring μ-like (22.5kt)



Need to estimate syst. err. in MC expect.

Expected Allowed Region

10^{20} POT ~ 5 years



JHF Neutrino Working Group

Y.Itow, Y.Obayashi, Y.Totsuka (ICRR)
Y.Hayato, H.Ishino, T.Kobayashi, K.Nakamura, M.Sakuda (KEK)
T.Hara (Kobe)
T.Nakaya, K.Nishikawa (Kyoto)
T.Hasegawa, K.Ishihara, A.Suzuki (Tohoku)
A.Konaka (TRIUMF)

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

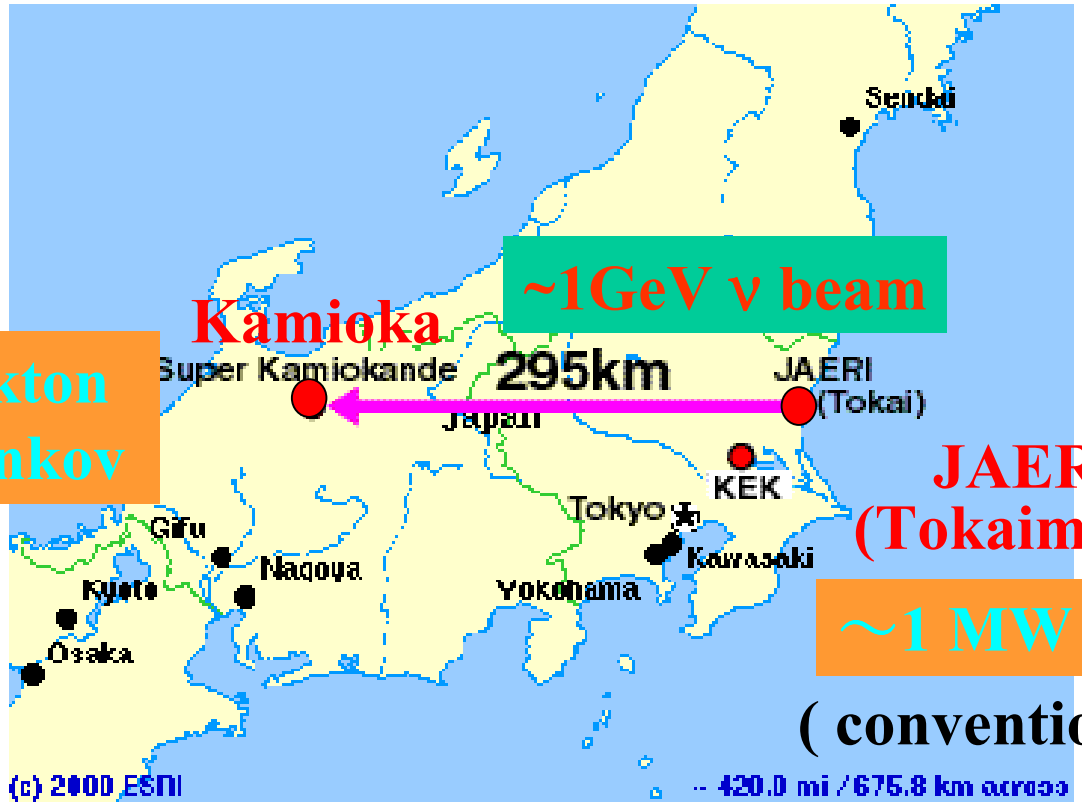
Physics motivation

1. **Test our current picture of 3 flavor neutrino oscillation**
   - Spectrum shape of ν_μ disappearance
     - Test exotic models (decay, extra dimensions,….)
   - Appearance of ν_e at the same Δm^2 as ν_μ disappearance
   - NC measurements
     - No additional "neutrino"?
2. **Precise measurement of Δm^2 and mixing angles (θ_{23}, θ_{13})**
   - mixing matrix in quark sector: well known
   - understanding of mixing in lepton sector
   - understanding of mass structure

   → hints on physics beyond the SM (GUTs,…)
3. **Discovery of ν_e appearance**

   → Open possibility to detect CPV effect in lepton sector

Overview



Super-K: 50 kton Water Cherenkov

JAERI (Tokaimura)

~1 MW 50 GeV PS

(conventional ν beam)

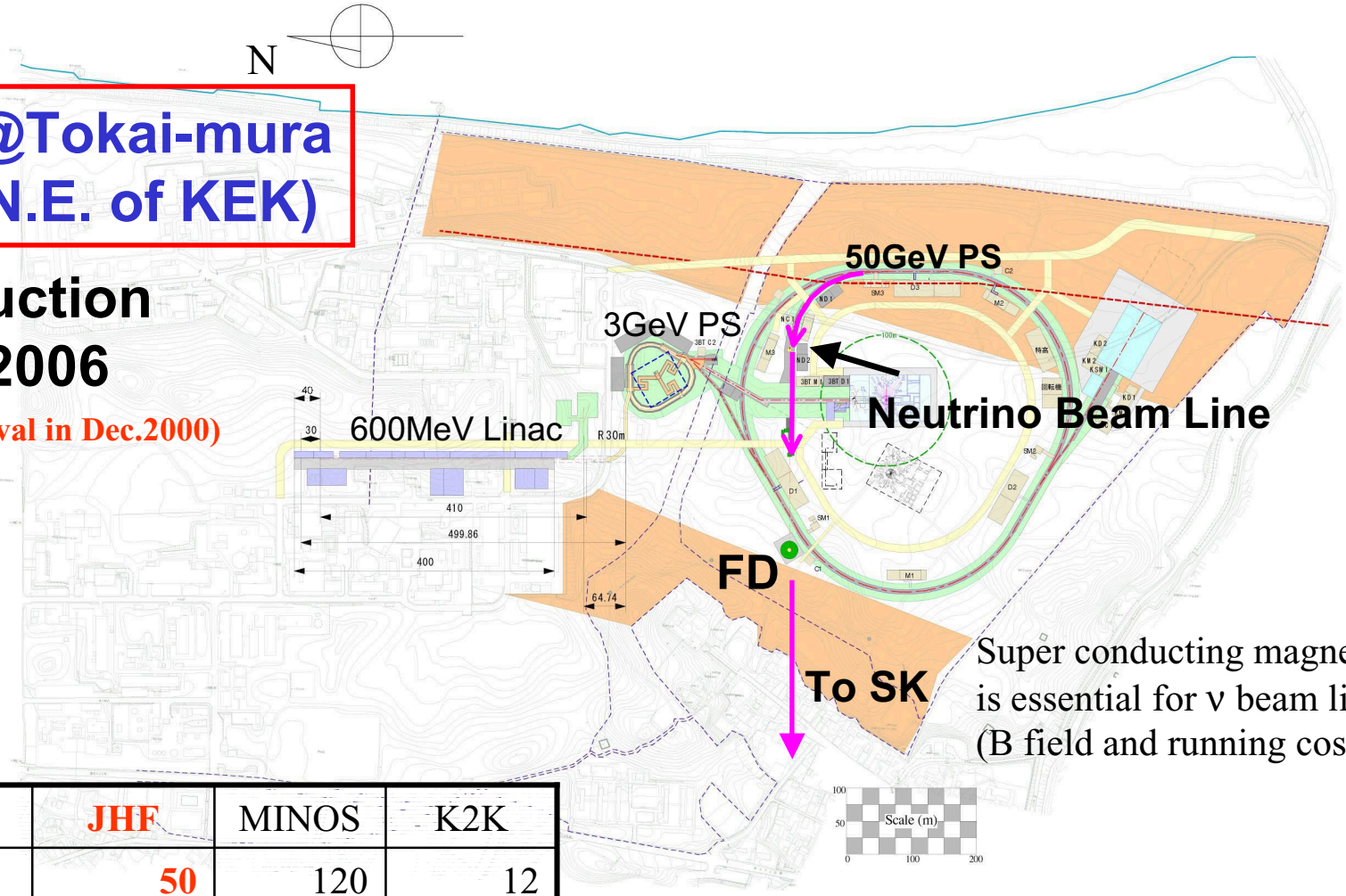
- $\nu\mu \rightarrow \nu x$ disappearance
- $\nu\mu \rightarrow \nu e$ appearance
- NC measurement

JHF project and neutrino beam line

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

Construction
2001～2006

(Expect approval in Dec.2000)



Super conducting magnet is essential for ν beam line (B field and running cost)

	JHF	MINOS	K2K
E(GeV)	50	120	12
Int.(10^{12}ppp)	330	40	6
Rate(Hz)	0.292	0.53	0.45
Power(MW)	0.77	0.41	0.0052

10^{21}POT(130day)≡ “1 year”

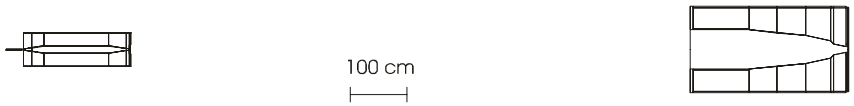
Neutrino Beam @ JHF

Three beam configurations

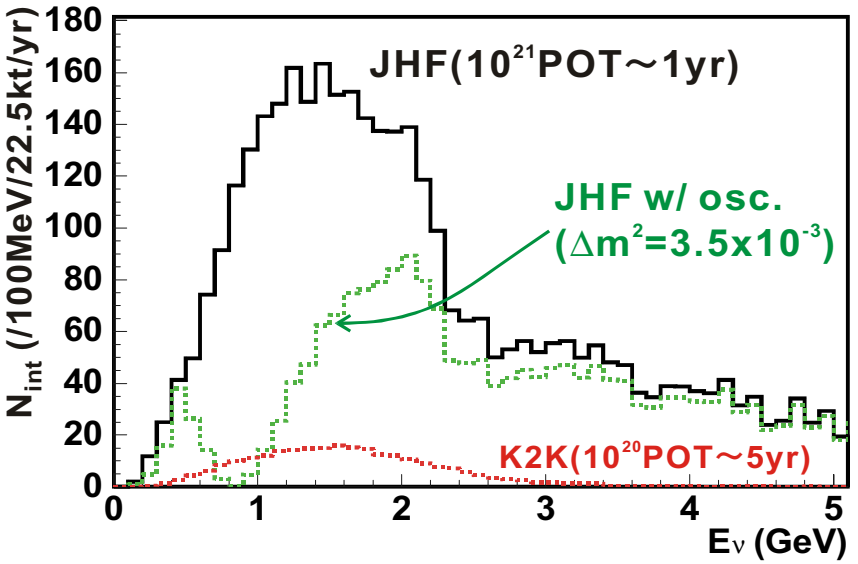
- **Wide Band Beam (WBB)**
  - 2 Horns almost the same as K2K
- **Narrow Band Beam (NBB)**
  - Horn(s) + Bending
- **Off Axis Beam (OAB)**
  - Another option of NBB

Wide Band Beam

Target : Cu 1cmϕ x 30cm
Horn : 250kA
Decay Pipe : 50m x 1.5mϕ
Gcalor

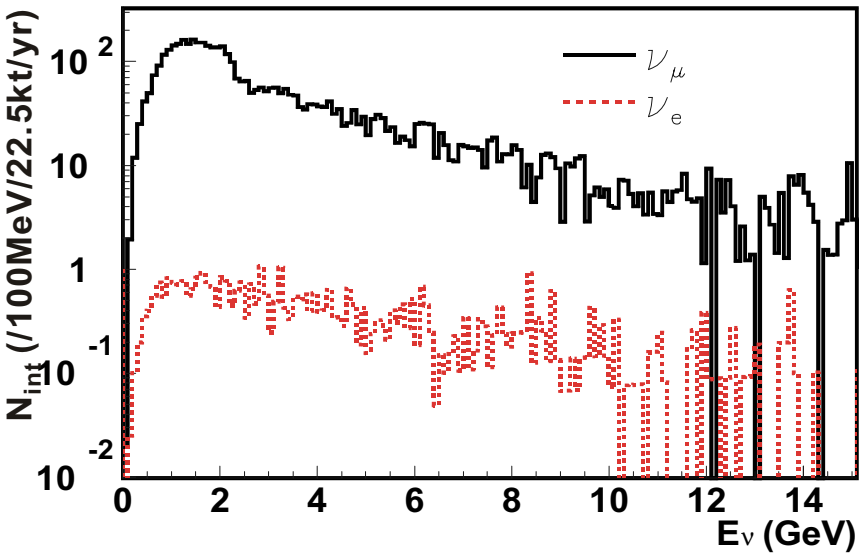


2 horns (almost same design as K2K)



~4200 ν_μ int./22.5kt/yr

ν_e:0.8%



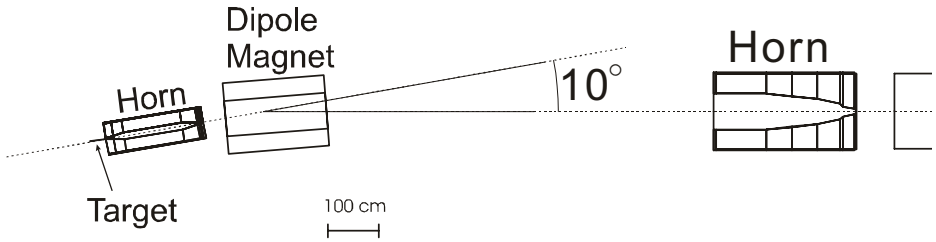
Intense
Wide sensitivity in Δm^2
BG from HE tail
Syst. err from spectrum extrapolation

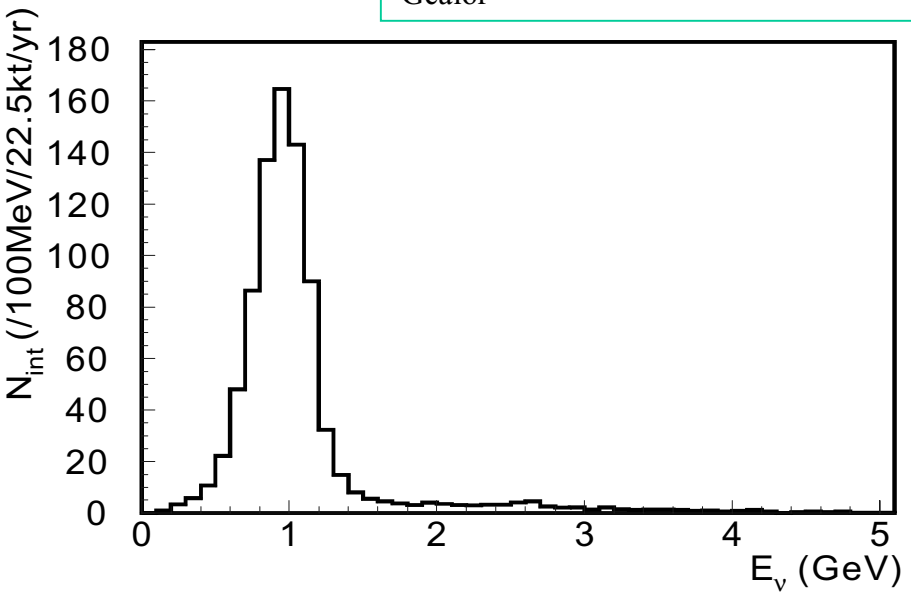
Narrow Band Beam

Updated from LOI

(factor ～2 increased by adding 2nd horn)

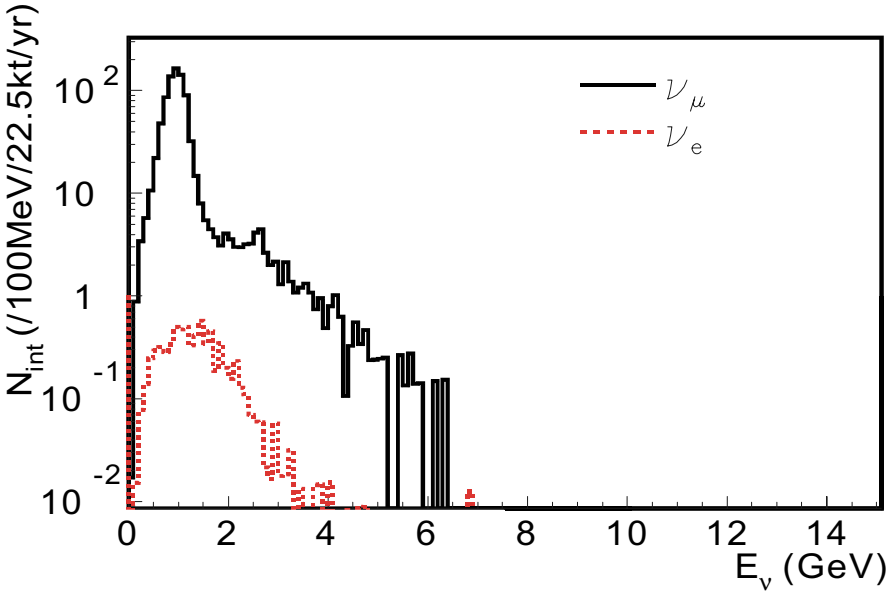
Target	: Cu 1cm$^{\phi}$ x 30cm
Horn	: 250kA
Decay Pipe	: 155m x 1.5m$^{\phi}$
Dipole	: 50cm(V)x70cm(H)x2m(L) 0.58T (10deg@2GeV/c)
Gcalor	





～830 int./22.5kt/yr

ν_e:0.8%(0.3% @ peak)



Less HE tail

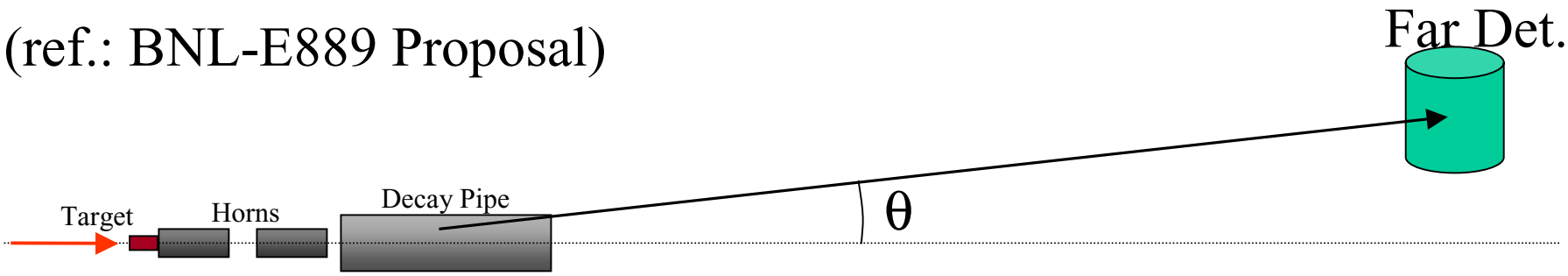
Less sys err from spectrum

"counting experiment"

Easy to tune E_ν

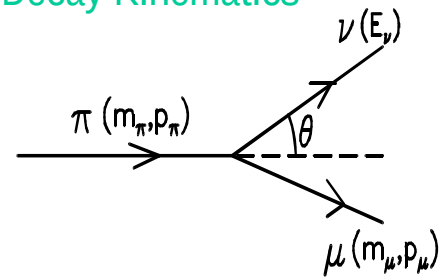
Off Axis Beam (another NBB option)

(ref.: BNL-E889 Proposal)

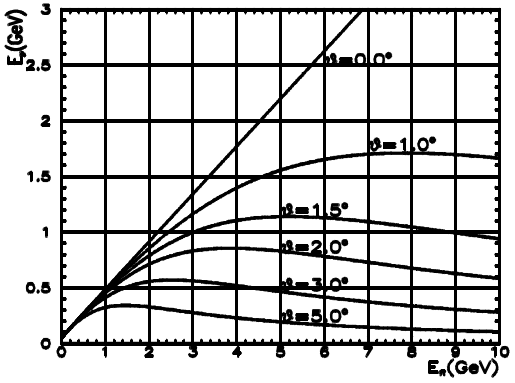


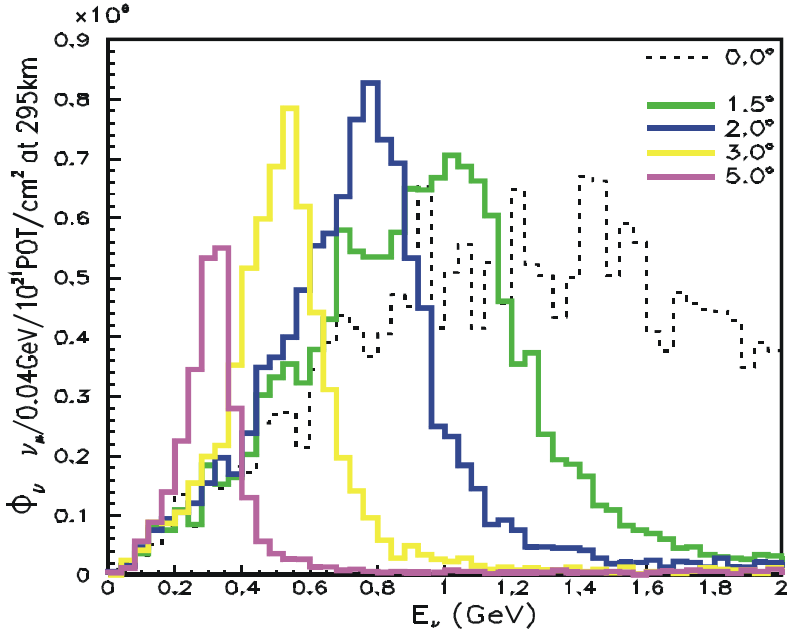
WBB w/ intentionally misaligned beam line from det. axis

Decay Kinematics



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





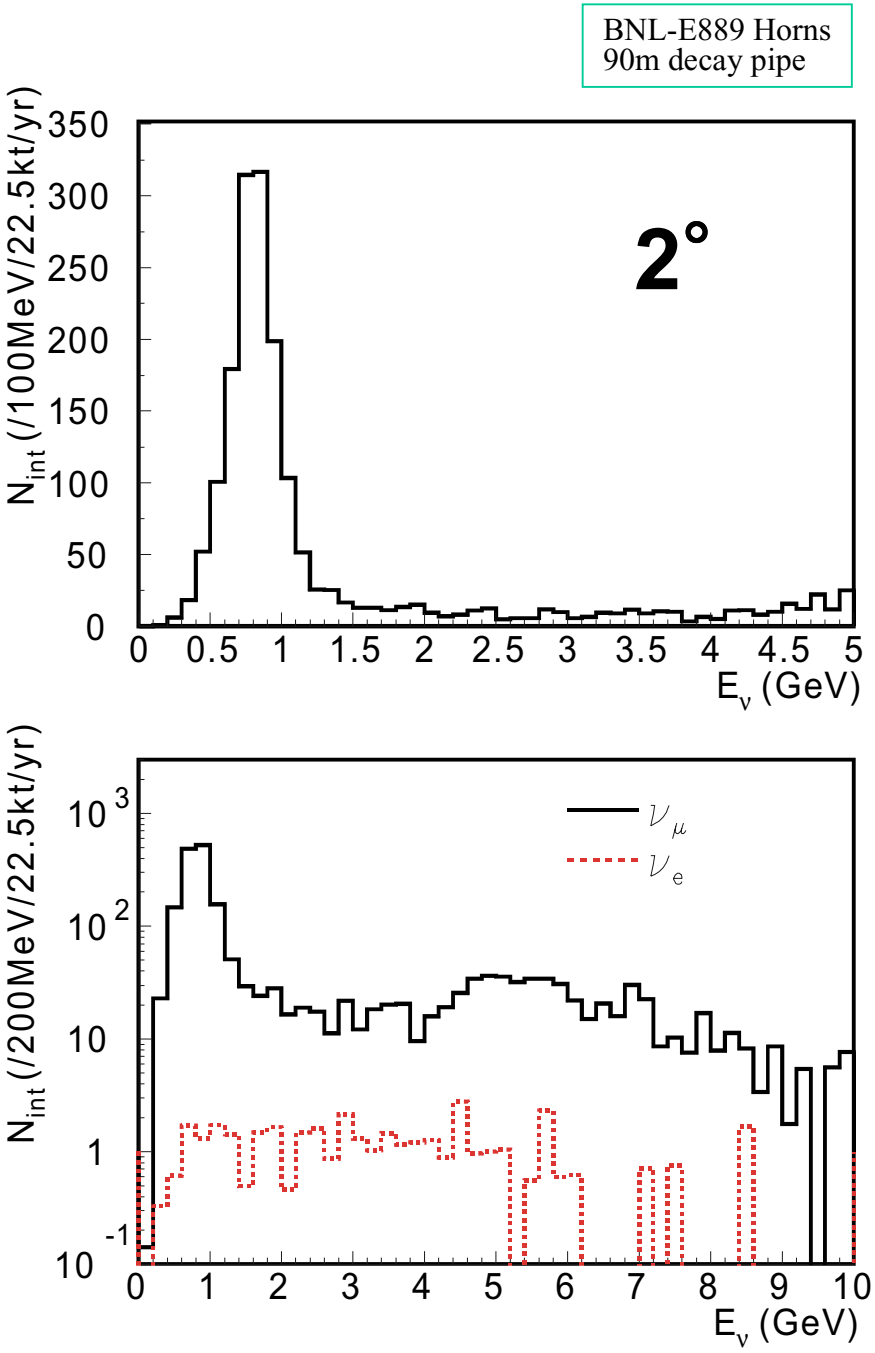
Quasi Monochromatic Beam

Off axis beam

~2200 int./22.5kt/yr

ν_e: 0.8% (0.2% @ peak)

High int. narrow band beam
More HE tail than NBB
Hard to tune E_ν



Strategy and Goal

- First 1 year WBB
  - → pin down Δm_{23}^2 to $\pm 10\%$ level
  - → NC measurement
- 5year NBB or OAB
  - → precise measurement of θ_{23} and θ_{13}.

Sensitivity (goal):

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

$\sin^2 2\theta_{13} \sim 5 \times 10^{-3}$ (90% CL)

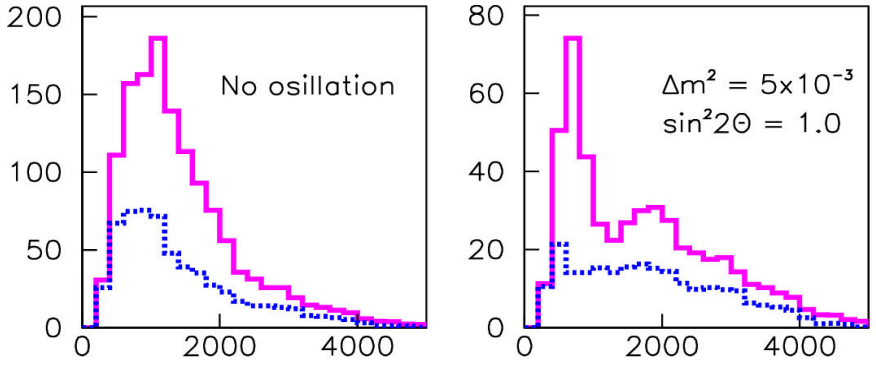
$\delta \Delta m_{23}^2 \sim 1.5 \times 10^{-4} \mathrm{eV}^2$

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

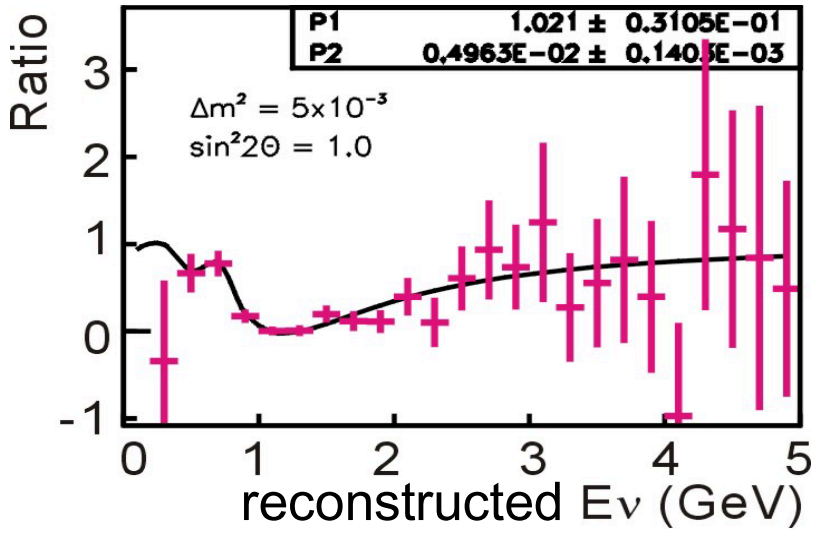
ν_μ disappearance

1ring FC μ-like

Total
Inelastic



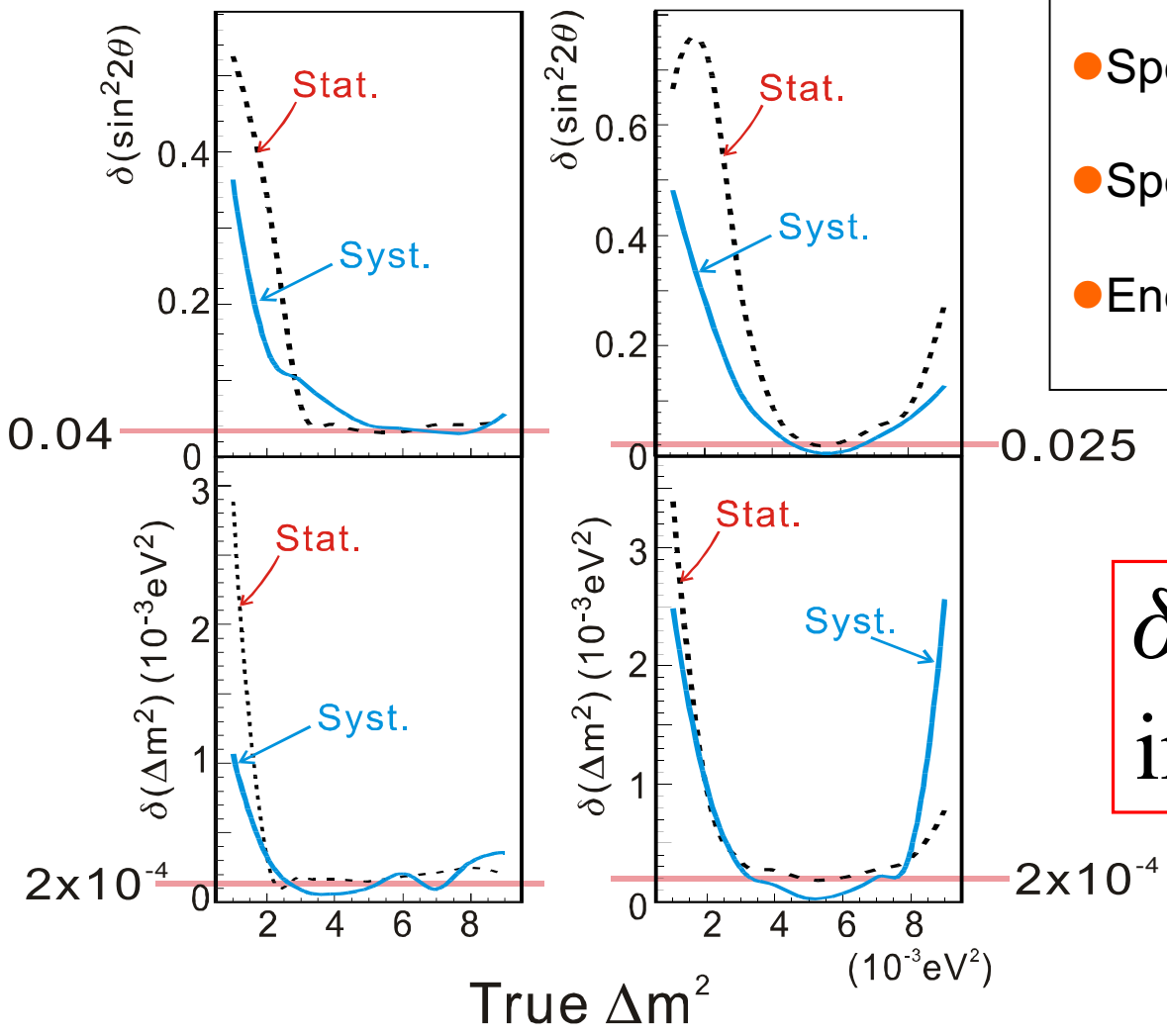
Ratio aft. BG subt.



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

ν_μ disappearance

1year



Possible syst. errors

- Inelastic cross section
  20%
- Spectrum measured at FD
  4%E
- Spectrum difference (near to far)
  10%
- Energy measurement
  3%

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

ν_e appearance (θ_{13})

- Signal
  - 1ring e-like ring
  - At energy of ν_μ disappearance dip
- Backgrounds
  - ν_μ NC π^0 production
    - Lower E photon is missed
  - Beam ν_e comtamination
    - Broad E dist. Can be reduced w/ energy window.
    - 0.2-0.3% of ν_μ at peak of NBB/OAB

Expected signal

$\sin^2 2\theta_{\mu e}$=0.05 (Chooz limit)

WBB

Sig: 49(ε=18.4%)
BG: 20(ε=0.1%)

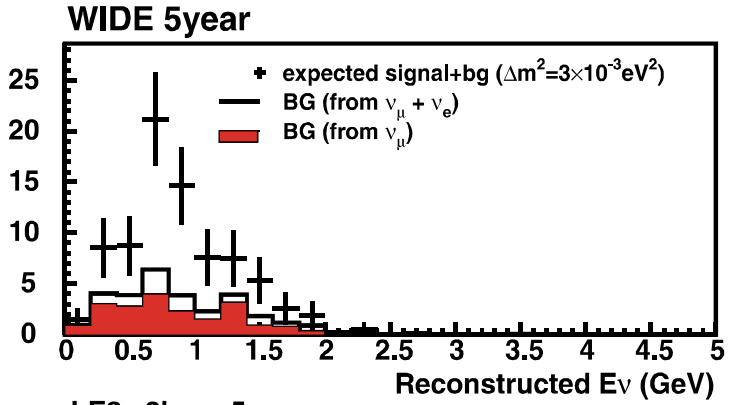
e/π^0 cut tightened to reduce BG

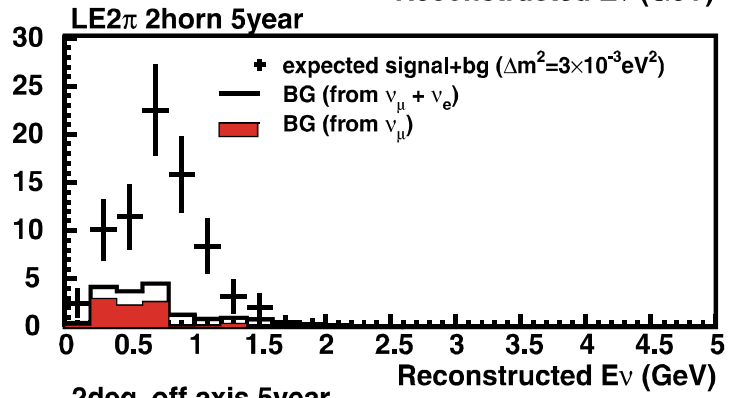
NBB

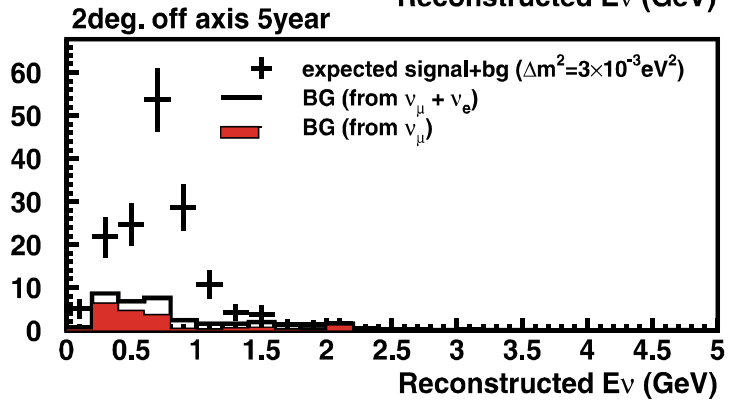
Sig: 58(ε=50.4%)
BG: 9(ε=0.2%)

OAB(2deg)

Sig: 121.5(ε=53.4%)
BG: 19(ε=0.2%)

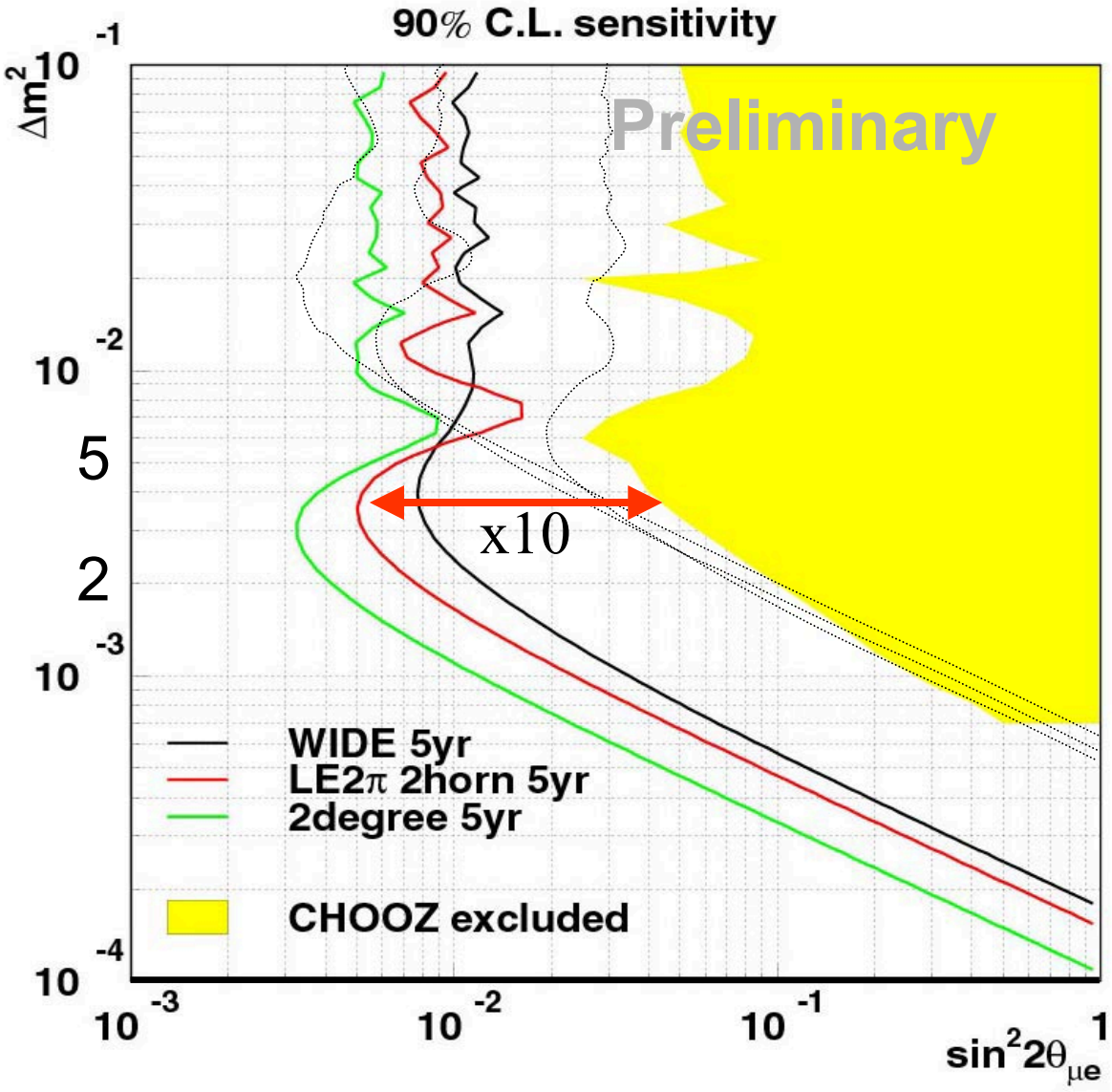






Preliminary

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



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

Future Extensions

- **PS upgrade to 4MW and 1Mton water Cherenkov detector**
  - 2 order increase in statistics
  - CPV if ν_e appearance discovered in the 1st phase
    - O(100) ν_e events/year if θ_{13}=0.1x(Chooz limit)
  - (Proton decay)
- **Very LBL experiment (1000-2000km)**
  - ～300(1200)CC events/100kt/yr @ 2000(1000)km w/ 6GeV NBB
  - Sign of Δm^2s
  - Matter effect
  - CPV

Summary

K2K

- **2.29×10^{19}POT** @ SK from Jun '99 to Jun '00
- Neutrino beam is well under control
  - Direction: within 1mrad
  - Spectrum: stable within stat. error
  - Intensity: stable within stat. error
  - Pi mon proved MC spectra ratio
- # of fully contained events in fiducial volume @ SK

  Observed: 27

  Expected : $40.3^{+4.7}_{-4.6}$ (w/o osc.)
- Experiment will resume **Jan. 2001**

JHF

- Low energy conventional ν_μ beam w/ MW 50GeV PS
- SK as far detector at L=295km
- E_ν tuned at osc. max.
- Great precision thanks to high intensity & large det.
  - ✓ $\delta \sin^2 2\theta_{23} \sim 0.01$
  - ✓ $\sin^2 2\theta_{13} \sim 5 \times 10^{-3}$ (90% CL)
  - ✓ $\delta \Delta m_{23}^2 \sim 1.5 \times 10^{-4} \mathrm{eV}^2$
    at ($\sin^2 2\theta = 1.0$, $\Delta m^2 = 3.2 \times 10^{-3} \mathrm{eV}^2$)
  - ✓ ν_s existence can be tested
- Design and R&D work have just been started.
- Expect data taking in 2006-7