ICEPP Sympo.
@ Hakuba
Feb 15-18, 2004

J-PARC Neutrino Experiment (T2K)

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January 2004

LOI to the J-PARC office (Jan, 2003)
Japan: 45, US:38, Canada: 19, Europe: 31, other Asia: 14

1. Introduction

- A next goal of neutrino experiments is to explore the neutrino oscillation phenomena beyond the discovery phase.
  - Three generation Matrix (NMS matrix)
  - CP Violation, matter effect, the sign of Δm_{23}^2
  - Unexpected physics behind the oscillation phenomena.

- More complete studies with high statistics by J-PACR neutrino experiment:
  - more precision
    - θ_{23}, Δm^2_{23}, oscillation curve, non-oscillation scenario
  - more sensitivity to a rare process
    - θ_{13} ($\nu_\mu \rightarrow \nu_e$), CP Violation, unexpected phenomena.

J-PARC Neutrino Experiment

(hep-ex/0106019)

Start at the beginning of 2009

J-PARC 0.75MW + Super-Kamiokande

(Future: Super-JPARC 4MW + Hyper-K ~ J-PARC+SK × 200)

Strategy

- High statistics by a high intense ν beam
- Tune Eν at the oscillation maximum
- Narrow band beam to reduce BG
- Sub-GeV ν beam for Water Cherenkov

0.75MW JHF 50GeV-PS
(4MW Super JHF)

Off-Axis ν beam

Super-Kamiokande
(Hyper-Kamiokande)

News

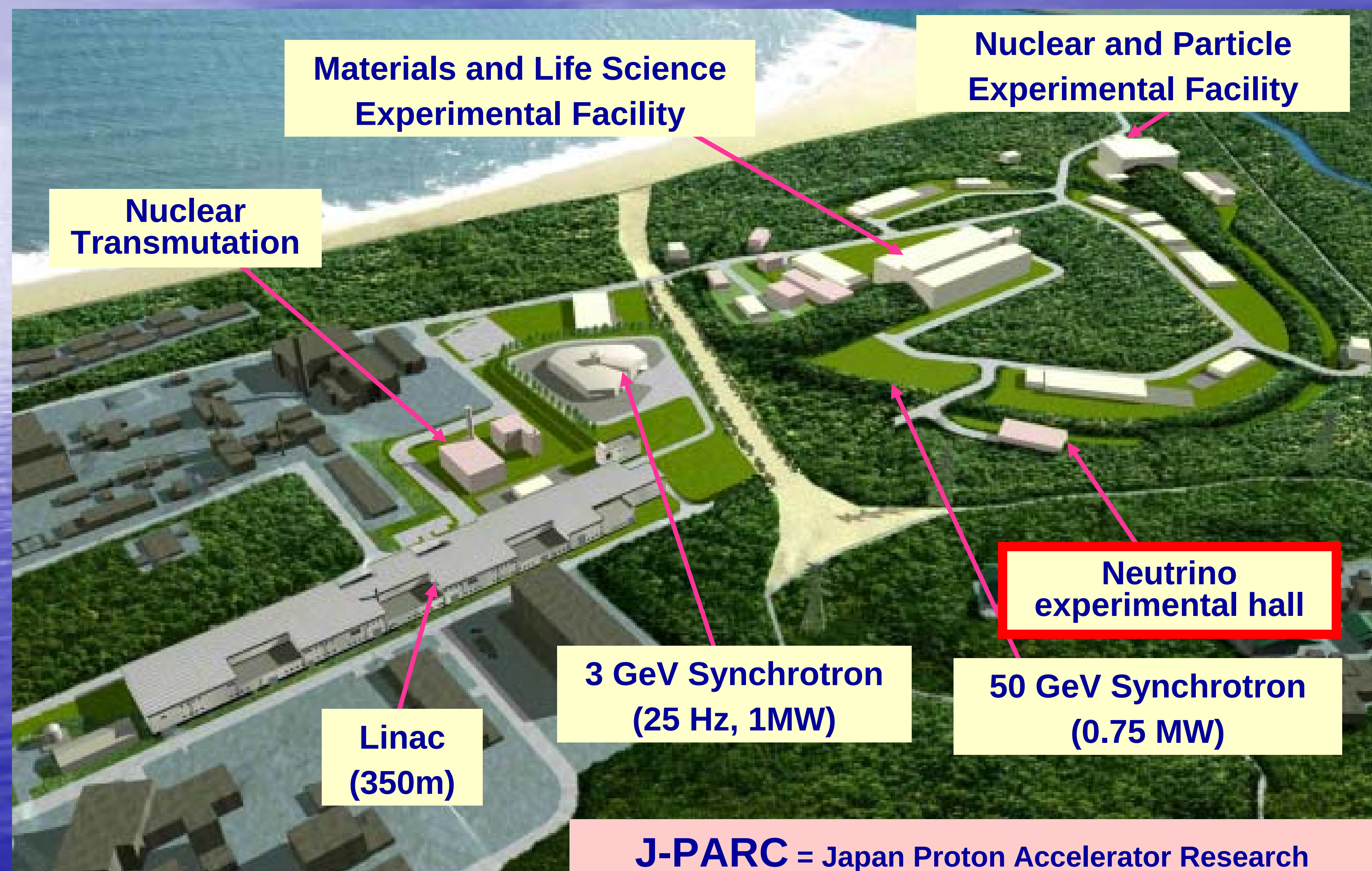
- **Dec.20,2003**
  - Neutrino project on the draft budget from MOF

J-PARC neutrino facility approved!

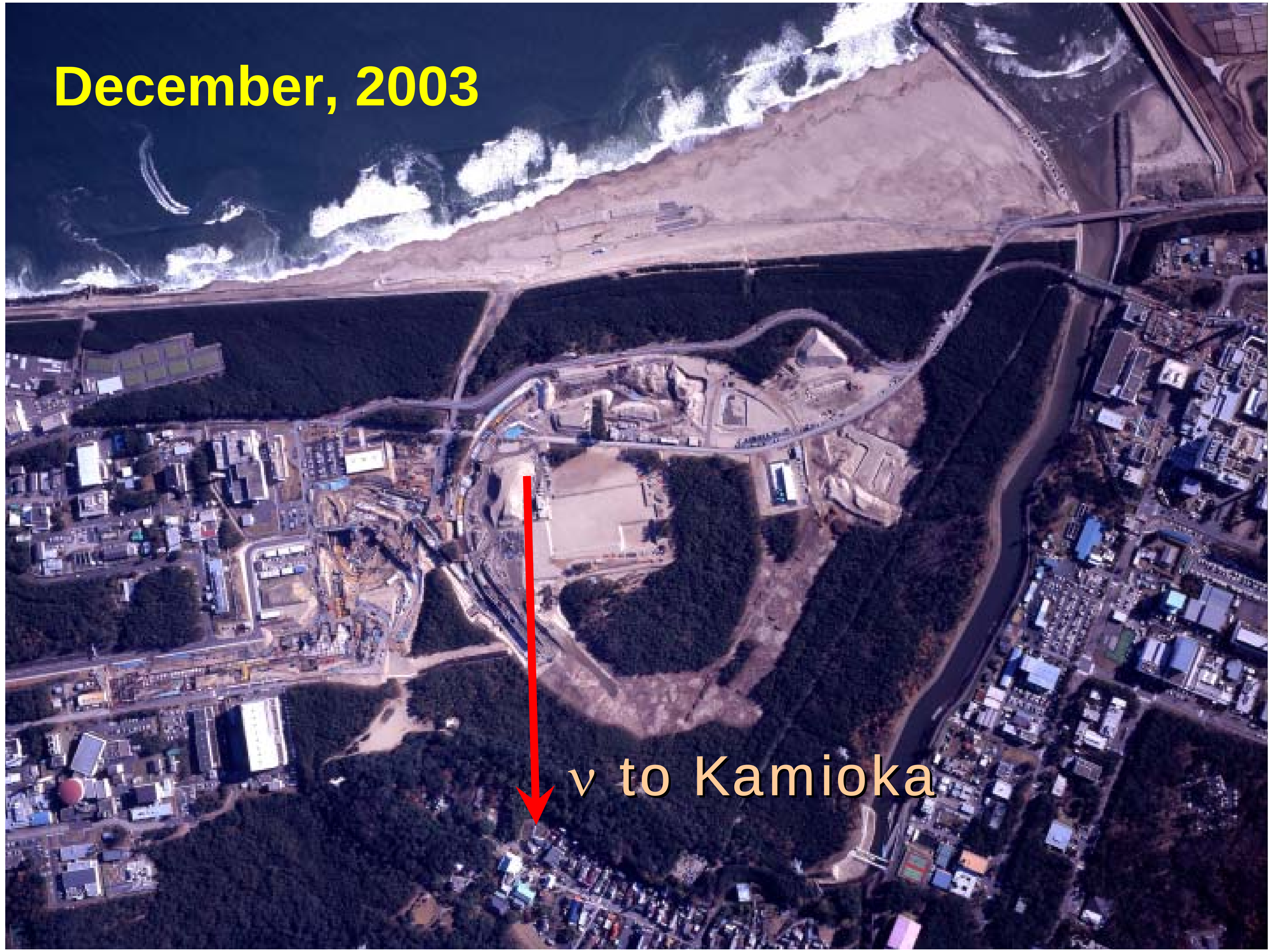
  - 5 years project from JFY2004 ~ JFY2008
  - Start the experiment at the end of JFY2008.

J-PARC (Japan Proton Accelerator Research Complex)

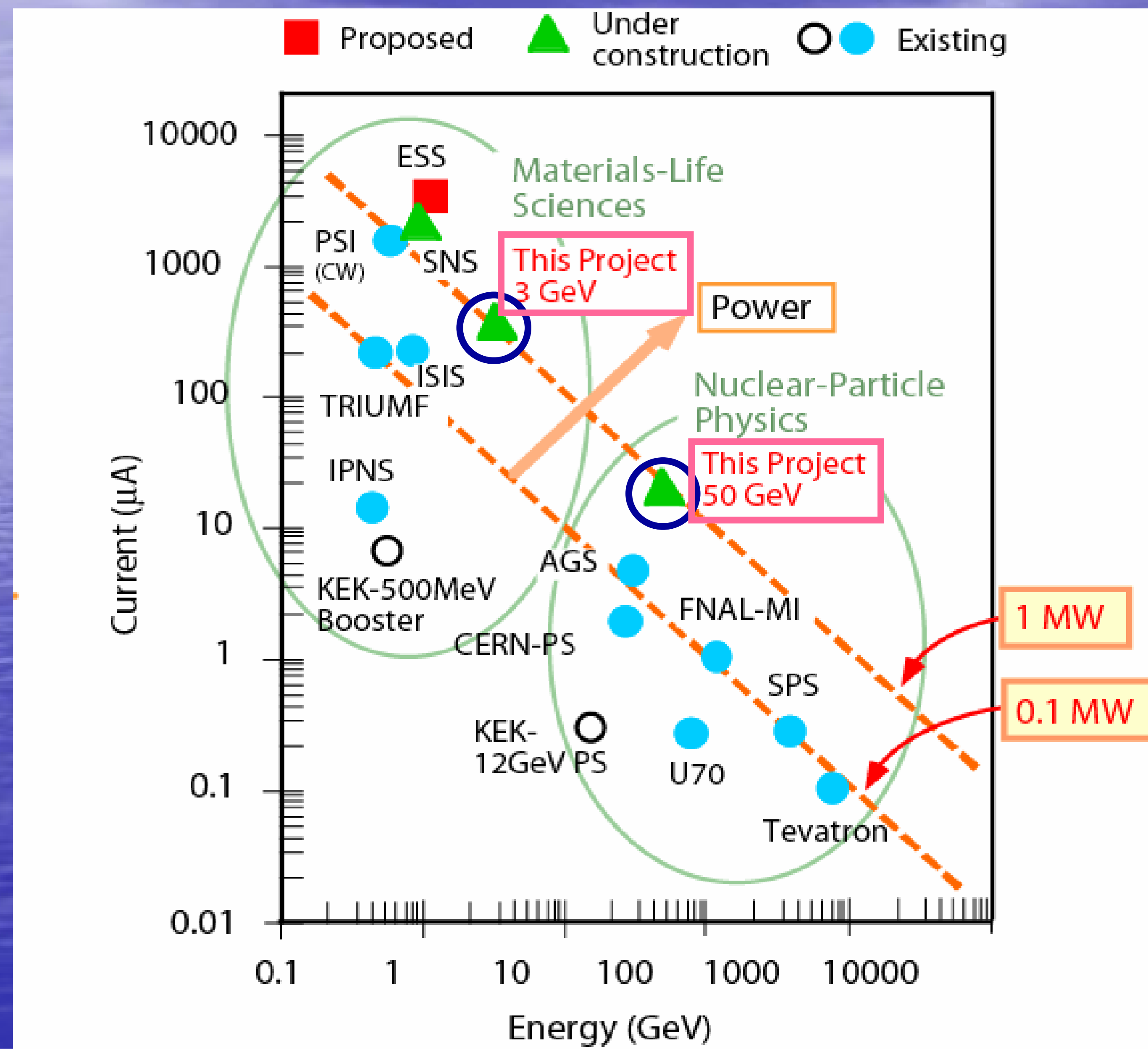
Construction started in 2001



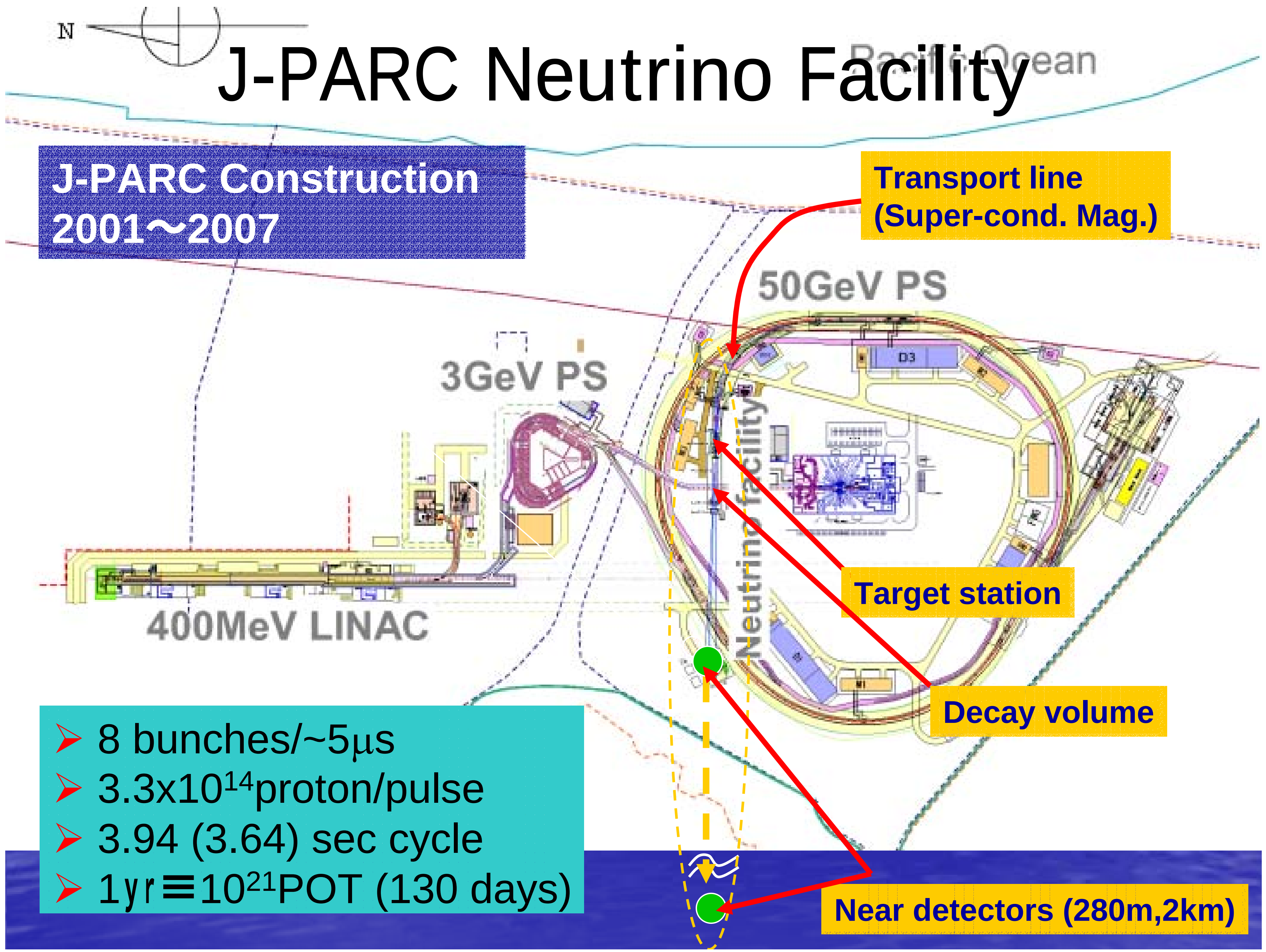
J-PARC = Japan Proton Accelerator Research Complex


December, 2003
ν to Kamioka

World's Proton Accelerators



J-PARC Neutrino Facility



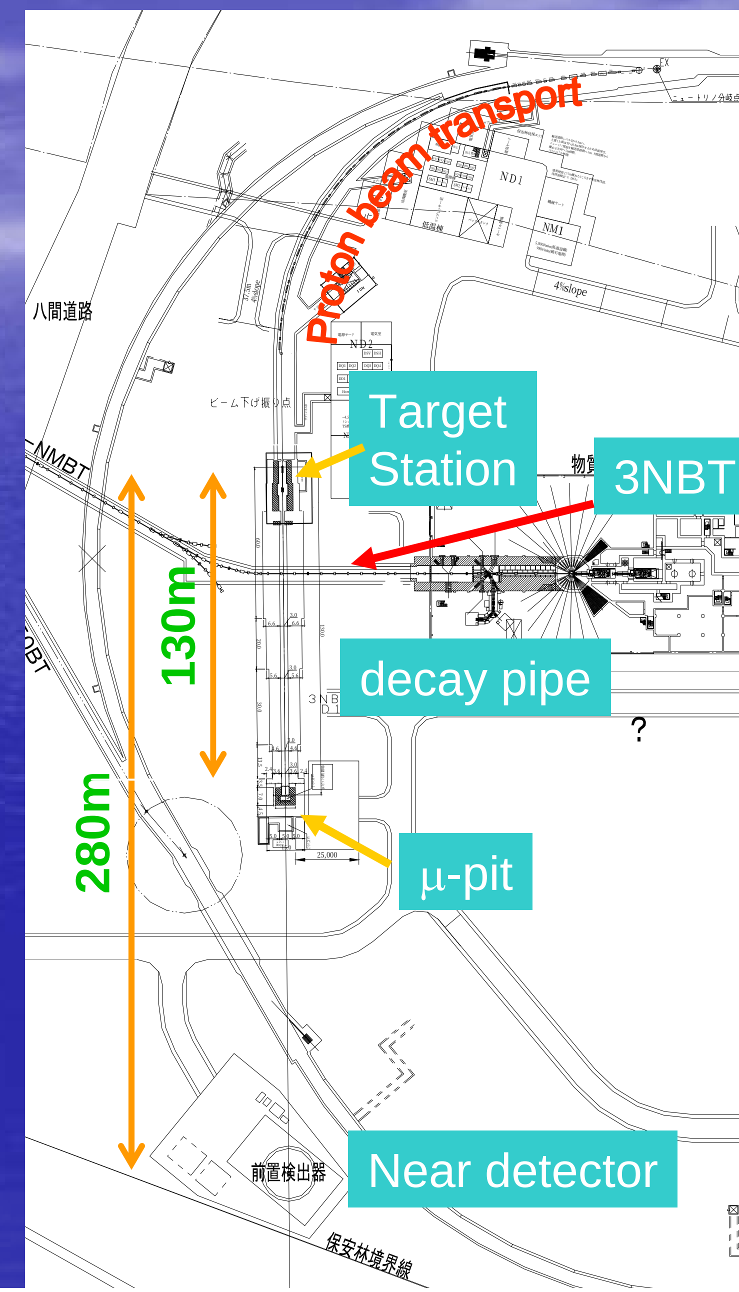
- 8 bunches/~5μs
- 3.3×10^{14} proton/pulse
- 3.94 (3.64) sec cycle
- 1yr≡10^{21}POT (130 days)

Special Features

- Superconducting magnets
- Off-axis beam

Components

- Primary proton beam line
  - Normal conducting magnets
  - Superconducting arc
  - Proton beam monitors
- Target/Horn system
- Decay pipe (130m)
  - cross w/ 3NBT
  - Cover Off-Axis angle 2~3 deg.
- Beam dump
- muon monitors
- Near neutrino detectors



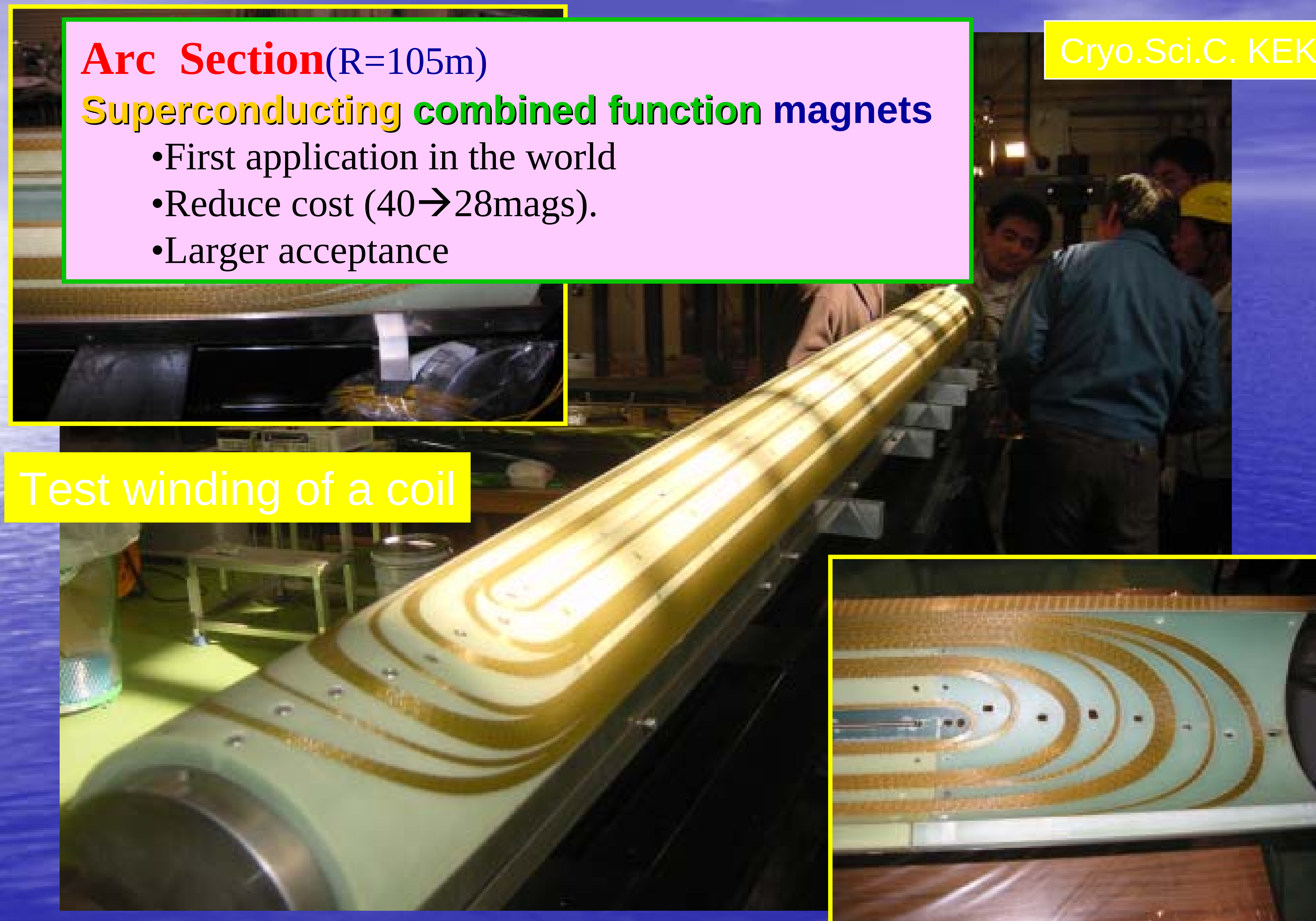
Development of Superconducting magnets

Cryo.Sci.C. KEK

Arc Section(R=105m)

Superconducting combined function magnets

- First application in the world
- Reduce cost (40→28mags).
- Larger acceptance



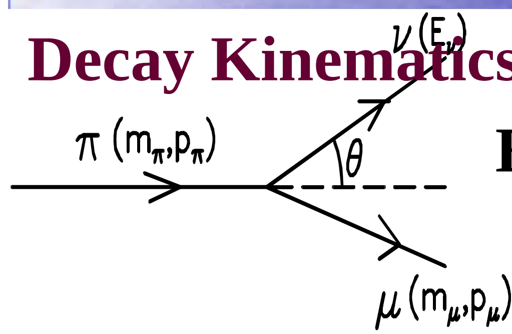
Test winding of a coil

Off Axis Beam (2° - 3 °)

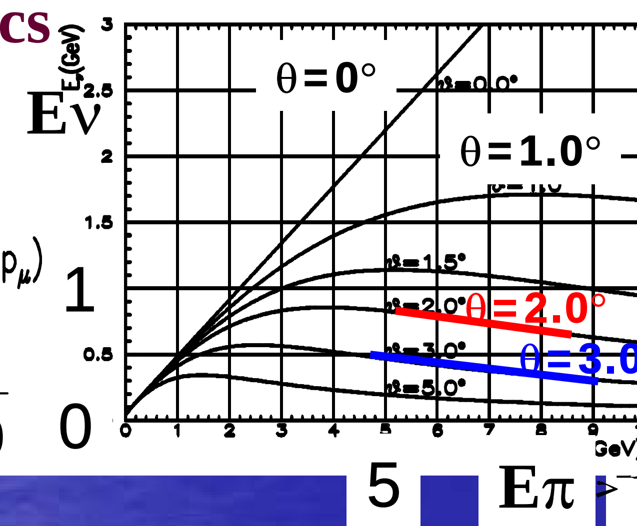
(ref.: BNL-E889 proposal: http://minos.phy.bnl.gov/nwg/papers/E889)

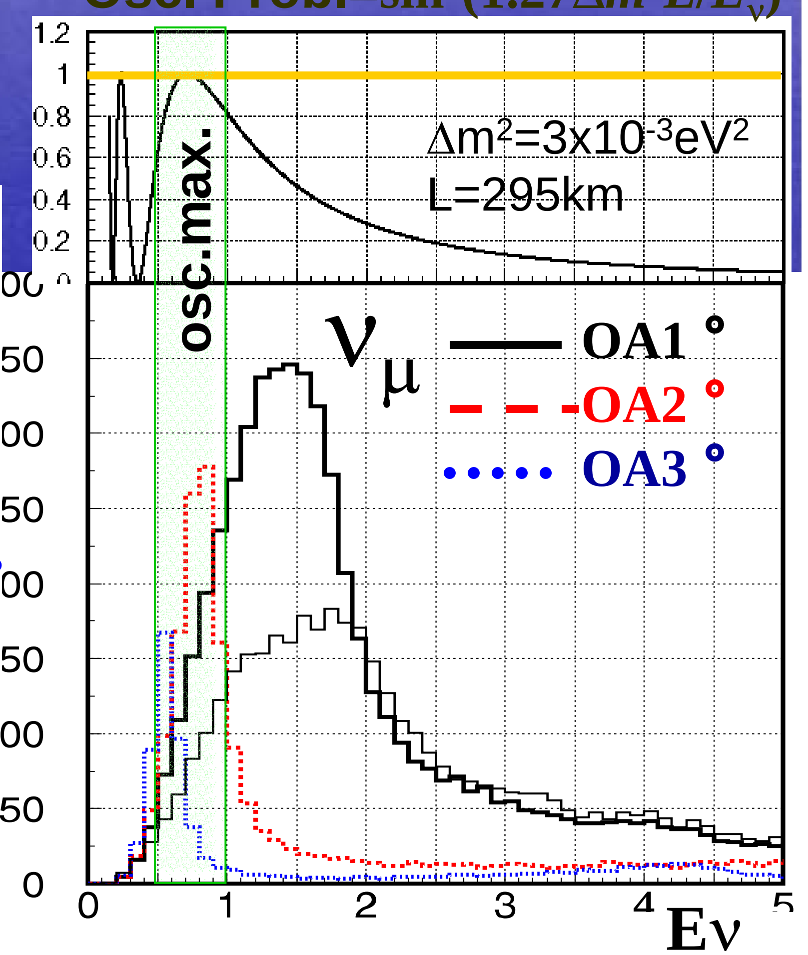
WBB w/ intentionally misaligned beam line from det. axis

Decay Kinematics



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

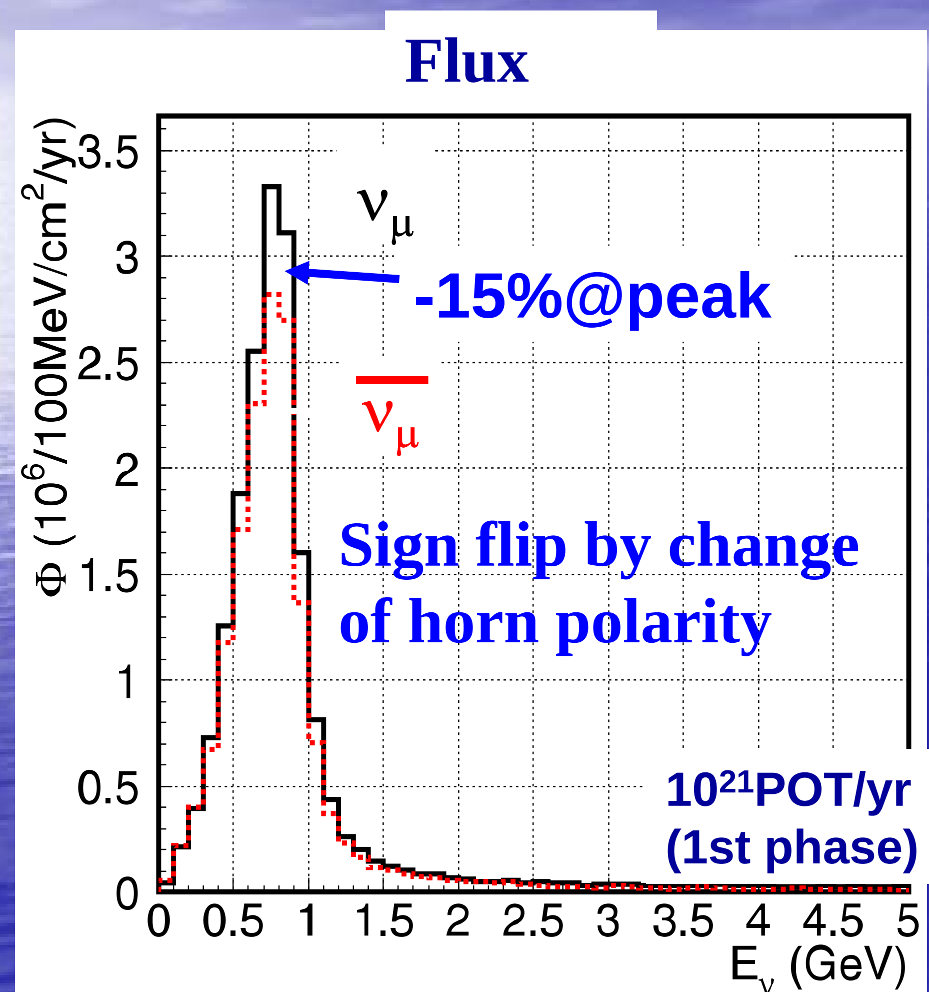


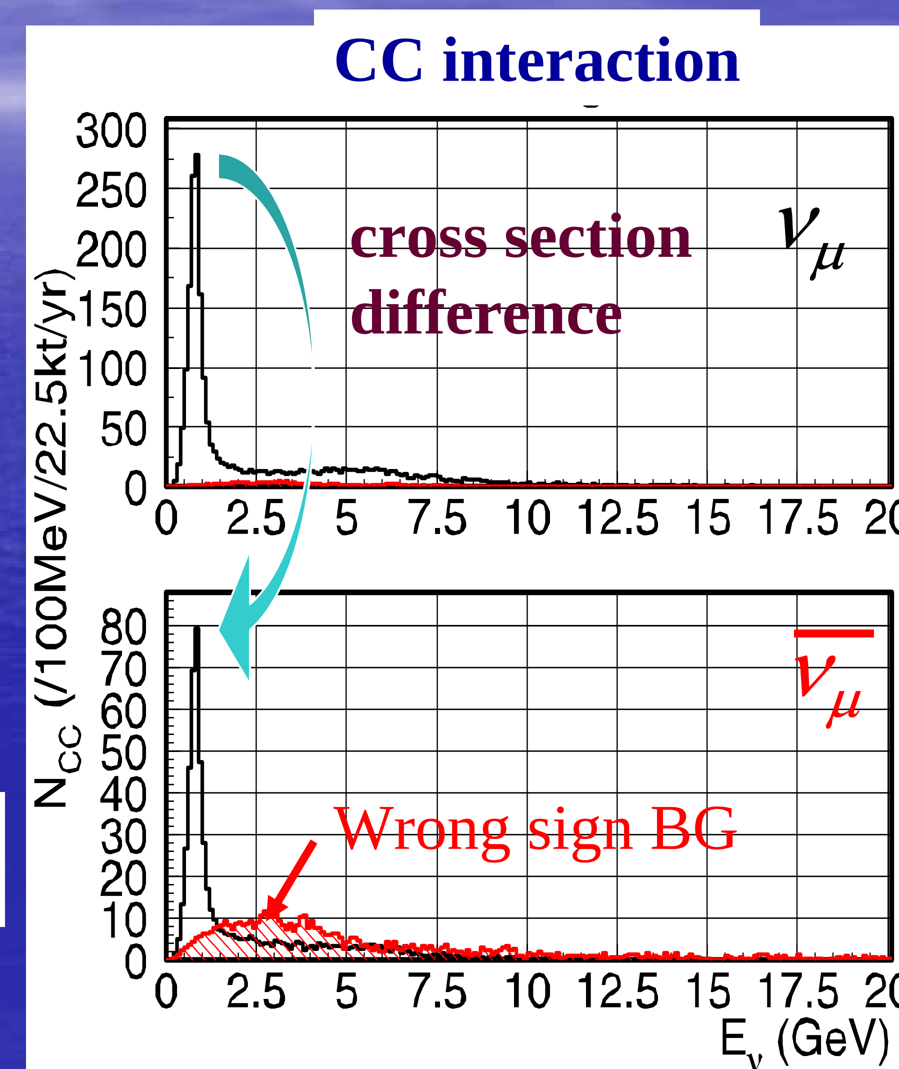


~3000 CC int./22.5kt/yr

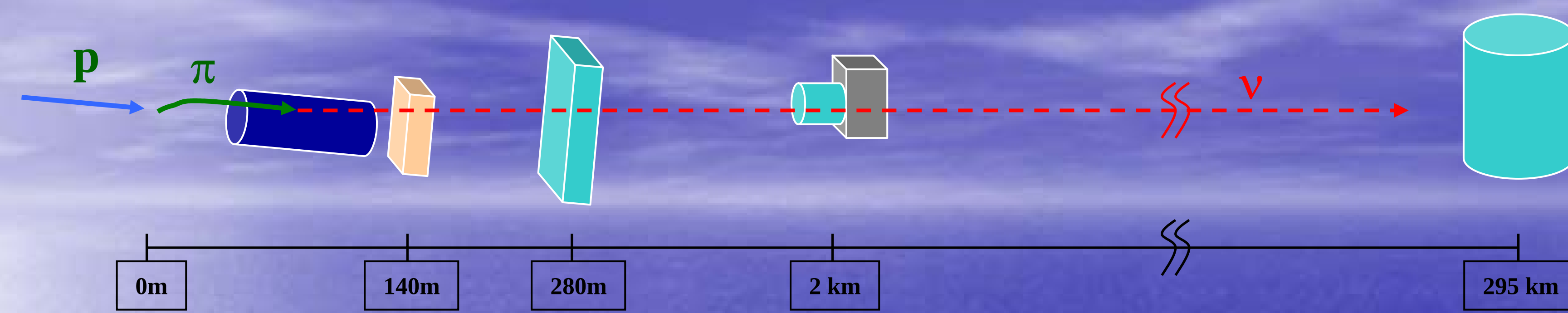
ν_e: 1.0% (0.2% @ peak);

$\nu_\mu/\overline{\nu_\mu}$ flux for CP violation search (2nd phase?)



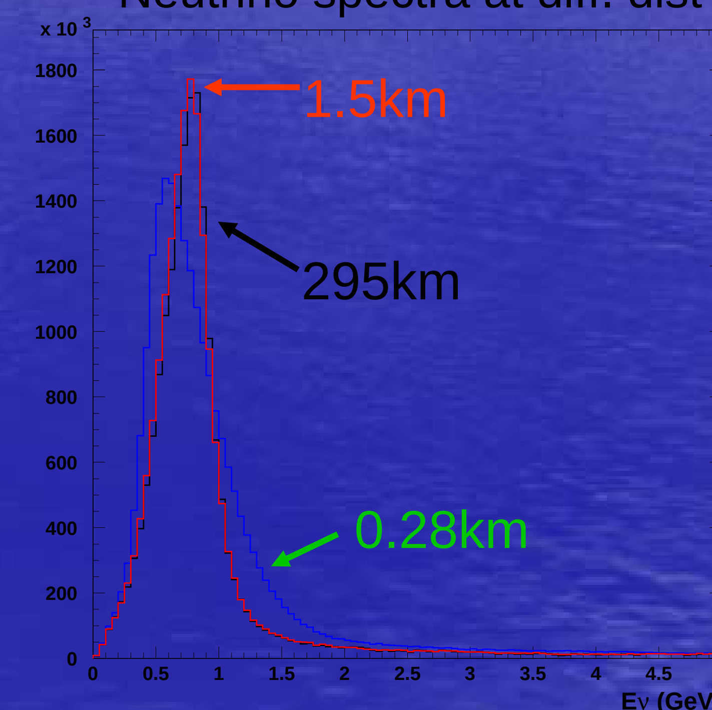


Detectors



- **Muon monitors @ ~140m**
  - Fast (spill-by-spill) monitoring of beam direction/intensity
- **First Front detector @280m**
  - Neutrino Fluxdirection
  - Study neutrino interactions.
- **Second Front Detector @ ~2km**
  - Almost same E_ν spectrum as for SK
  - Water Cherenkov can work
- **Far detector @ 295km**
  - **Super-Kamiokande (50kt)**

Neutrino spectra at diff. dist



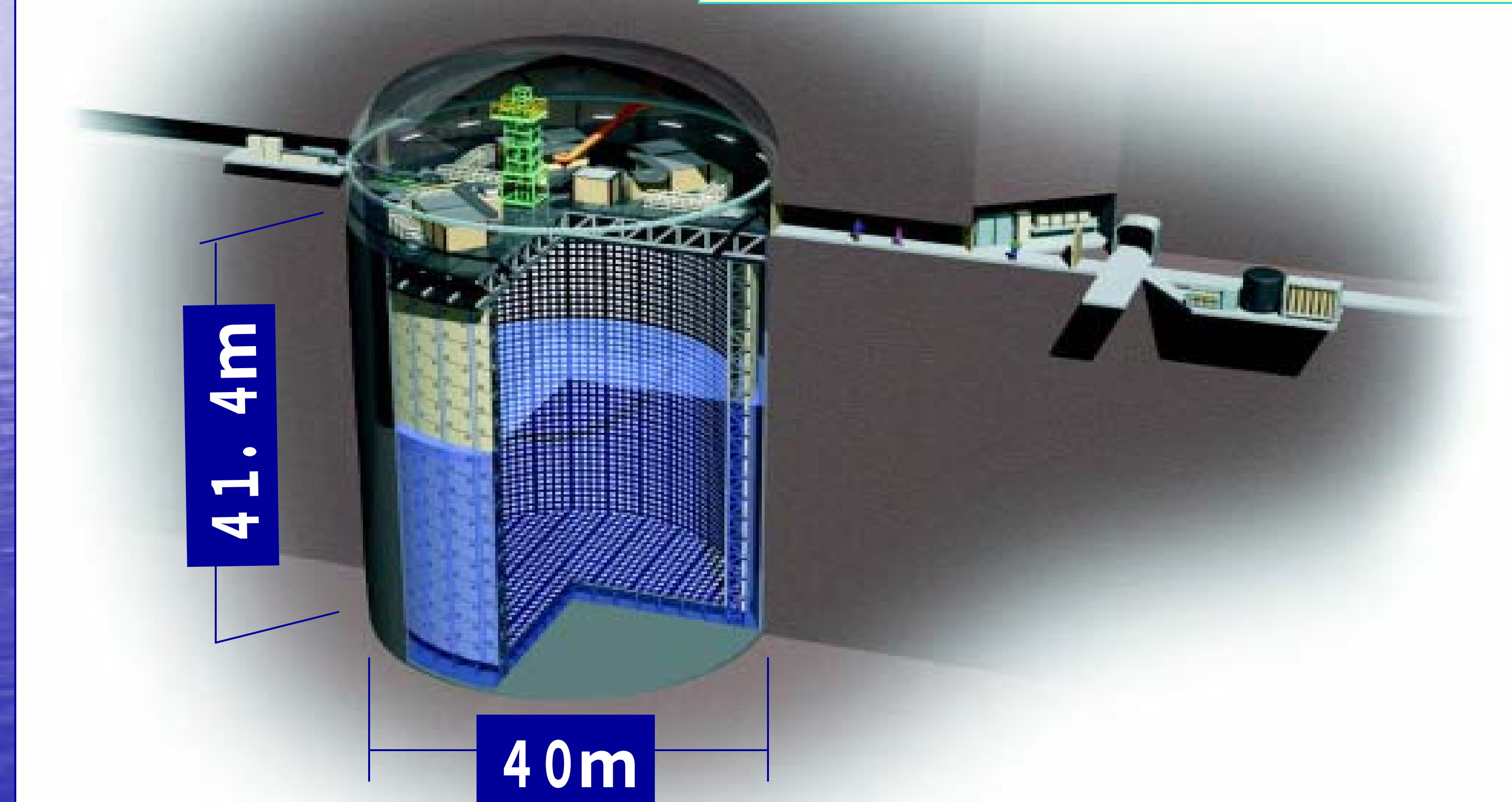
dominant syst. in K2K

Far detector Super-Kamiokande

(since Apr 1996)

50,000 ton water Cherenkov detector

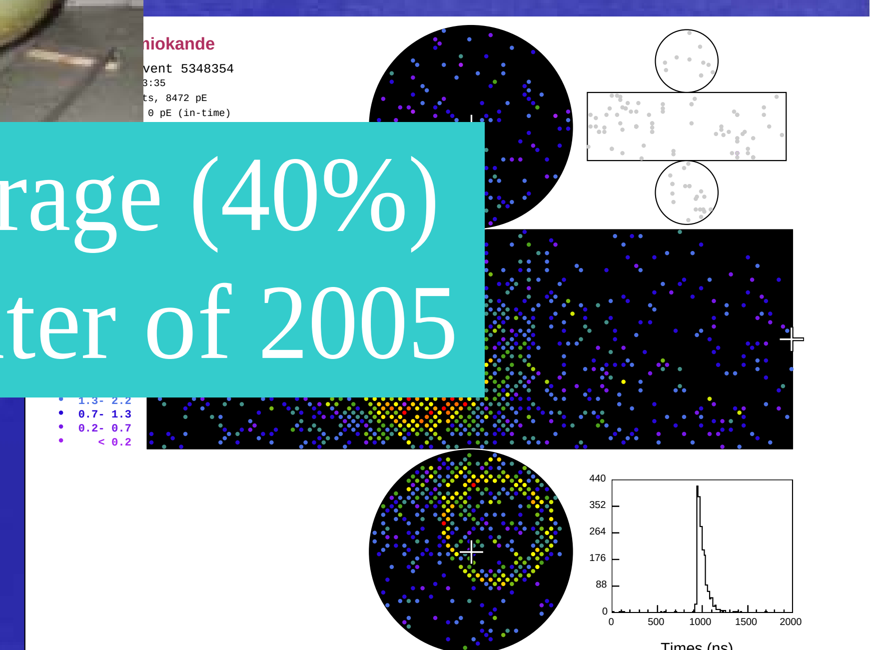
(22.5 kton fiducial volume)



Far detector SK is back !

Full water 10-Dec.-2002
w/ half coverage (20%)

Jan.-2003, fully contained event



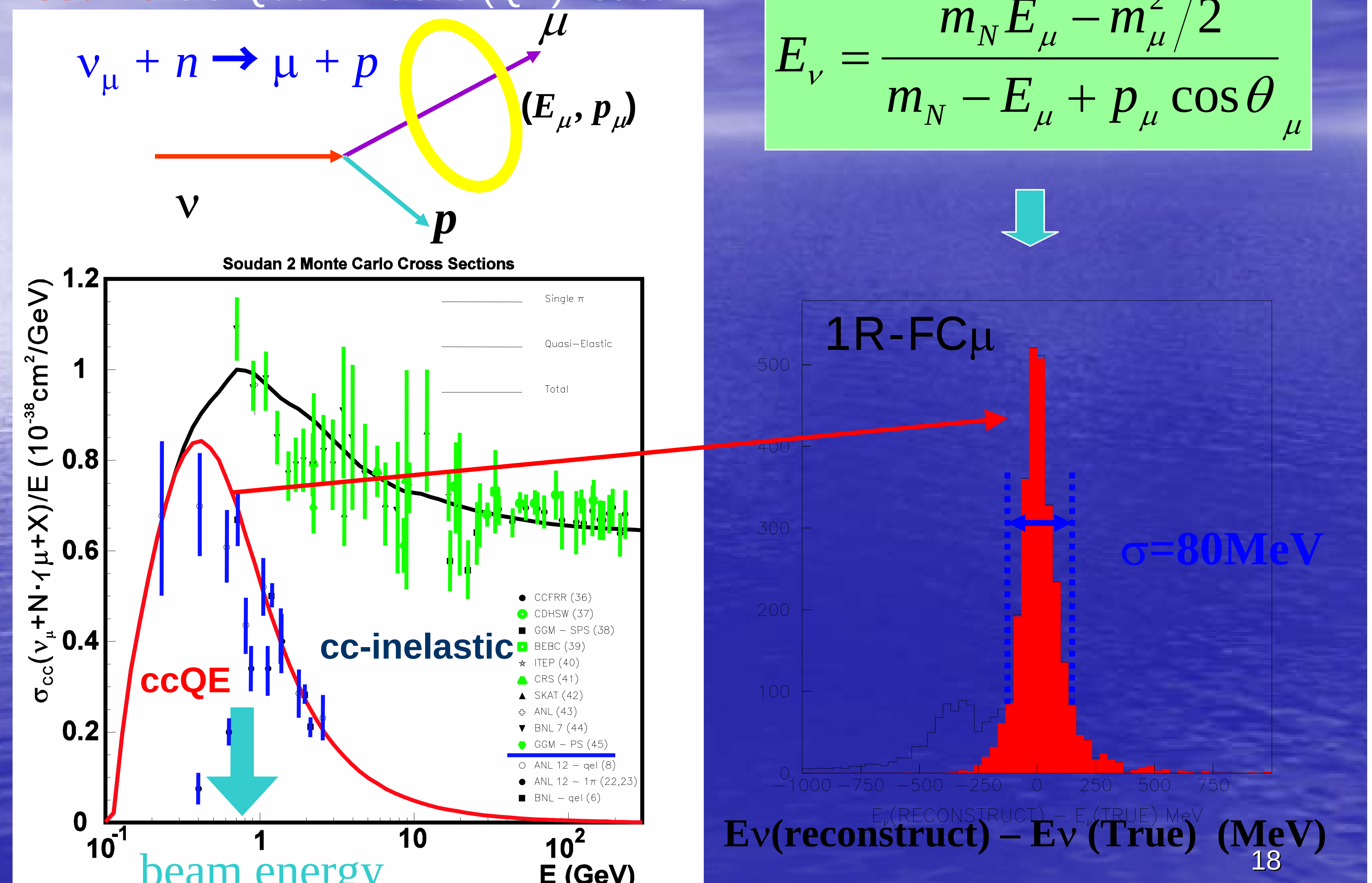
Back to full coverage (40%)
Scheduled in winter of 2005

Sep.-2002, before water filling

Eν reconstruction in Water Cherenkov

Assume CC Quasi Elastic (QE) reaction

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



Physics Goal at the 1st phase

★Precise measurement of neutrino mixing matrix

Accuracy: $\sin^2 2\theta_{23}$ ・・・・・・ 1%

Δm^2_{23}・・・・・・・・・・ a few % ($< 1\times10^{-4}$ eV^2)

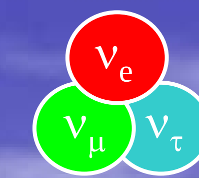
★Discovery and measurement of non-zero θ_{13}

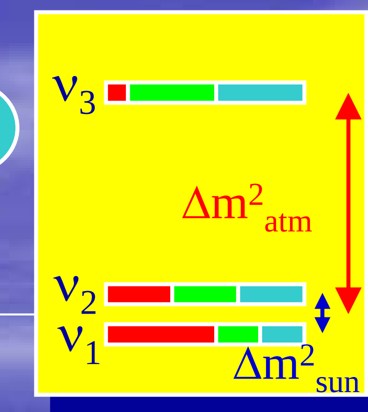
$\sin^2 2\theta_{13}$ ・・・・・・ > 0.006

1^{st} Evidence of 3-flavor mixing !

1^{st} step to ~~a~~ CP measurement

3-flavor Oscillation





Oscillation Probabilities when $\Delta m^2_{12} << \Delta m^2_{23} \approx \Delta m^2_{13}$

- θ_{23} : ν_μ **disappearance**

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

~1

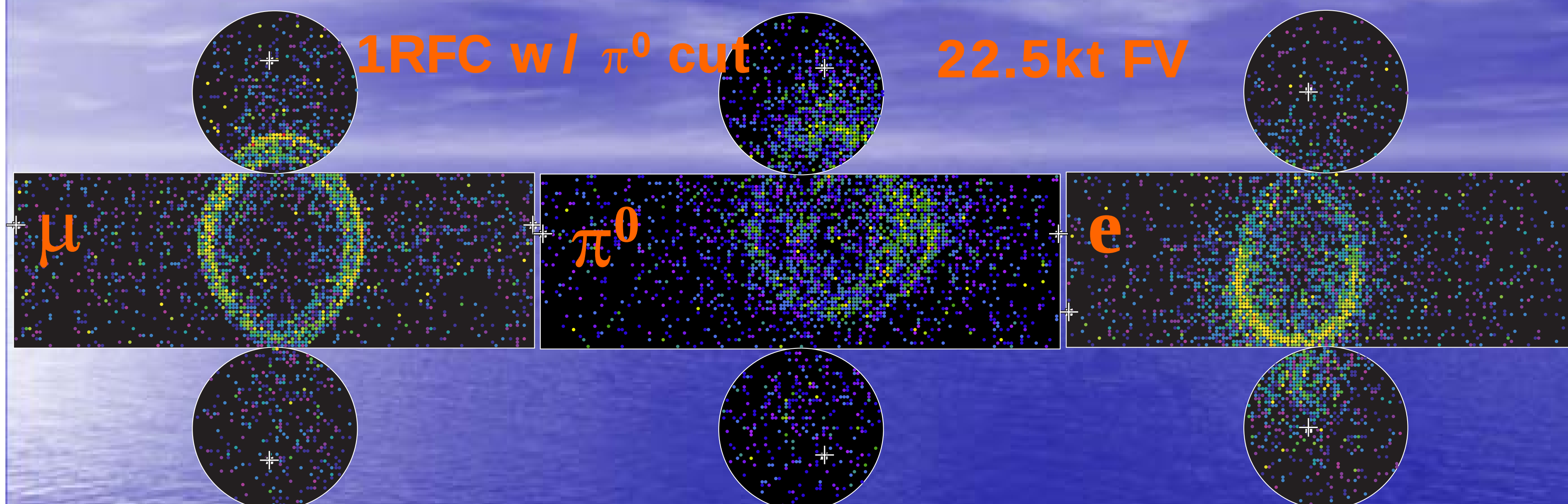
common

- θ_{13}: ν_e **appearance**

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

~0.5

ν_e appearance in T2K (phase 1)



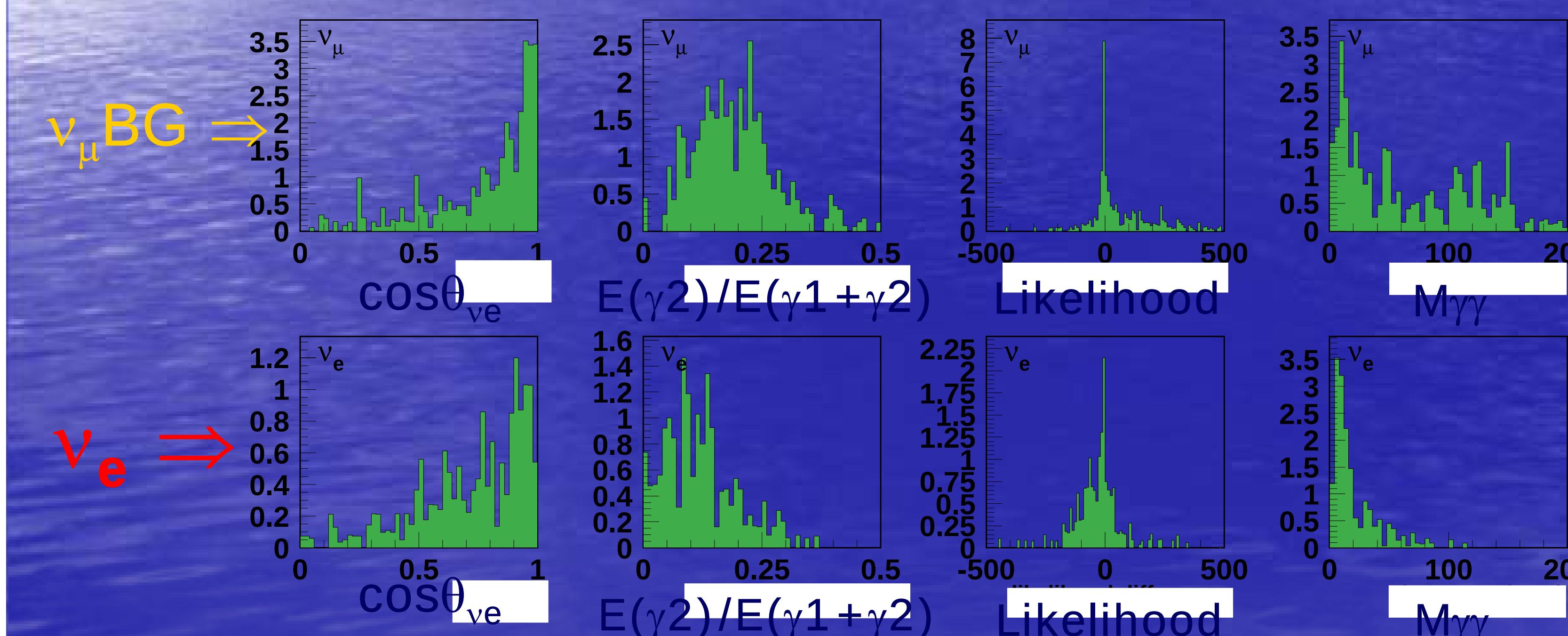
Back ground for ν_e appearance search

- Intrinsic ν_e component in initial beam
- Merged π^0 ring from ν_μ

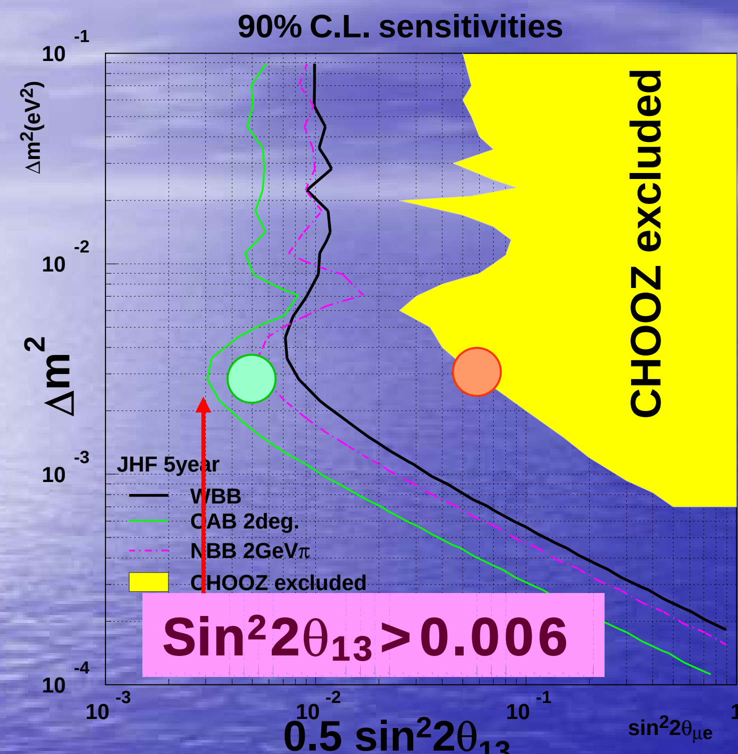
Requirement ➡ 10% uncertainty for BG estimation

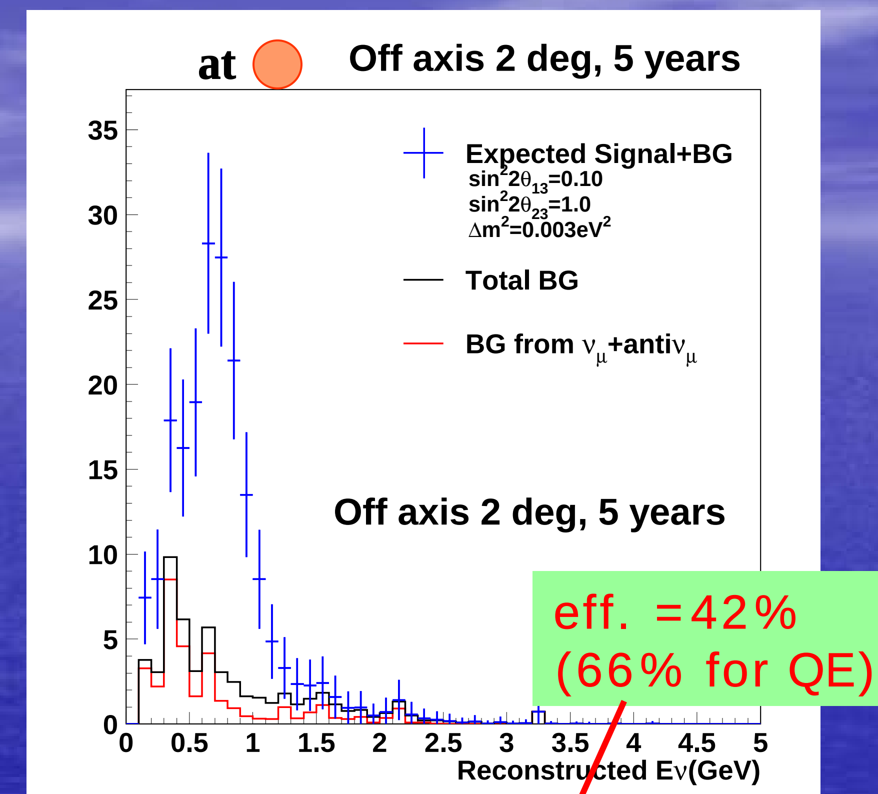
Tight e/π^0 separation

- Shower direction from the beam axis
  - $\cos\theta_{\nu e}$: γ from coherent π^0 tends to have a forward peak
- Force to find 2nd ring and…
  - $E(\gamma_2)/E(\gamma_1+\gamma_2)$: The second ring energy is larger for BG
  - Likelihood diff. between 1-ring and 2-rings
  - Invariant mass: Small for ν_e



$\sin^2 2\theta_{13}$ from ν_e appearance (5 years running)

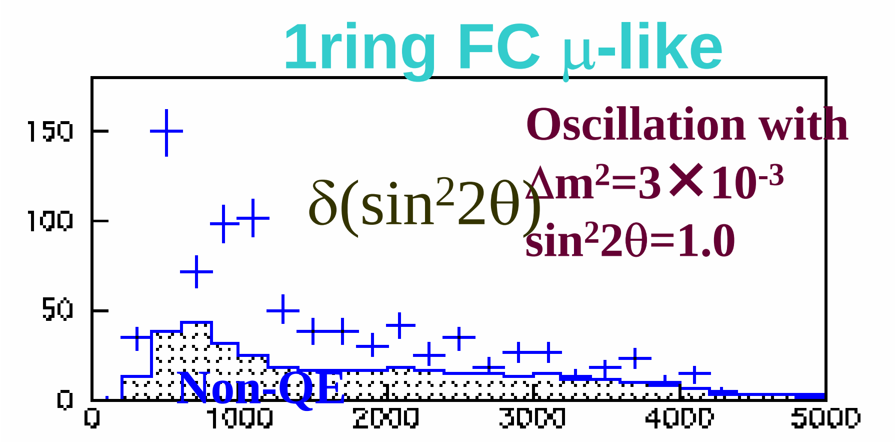


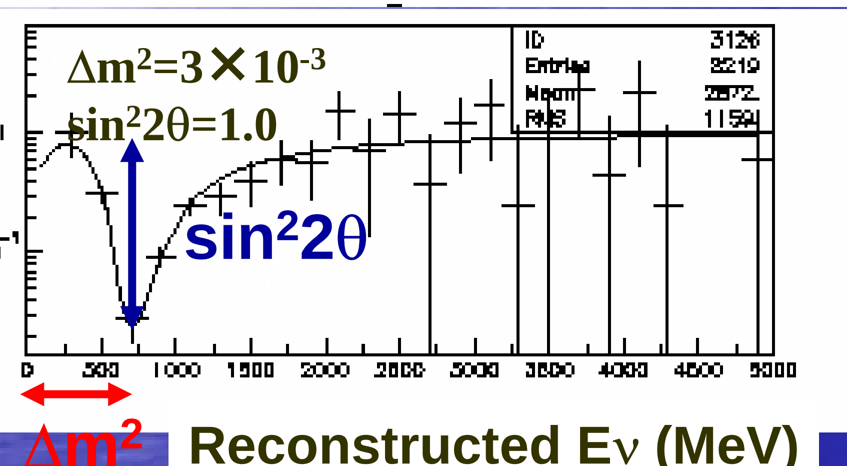


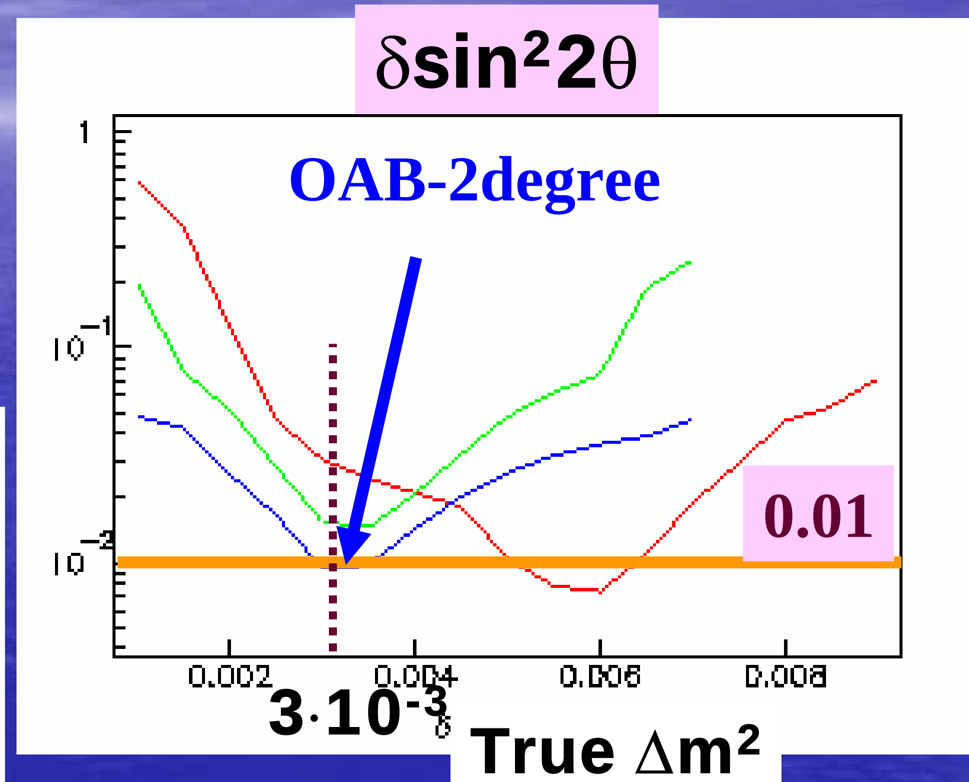
$\sin^2 2\theta_{13}$	Background in Super-K (as of Oct 25, 2001)					Signal	Signal + BG
	$\nu_\mu\ (\pi^0)$	ν_e	$\bar{\nu}_\mu$	$\bar{\nu}_e$	total		
0.1	12.0(*)	10.7	1.7	0.5	24.9	114.6	139.5
0.01	12.0(*)	10.7	1.7	0.5	24.9	11.5	36.4

(*) will be improved

ν_μ disappearance







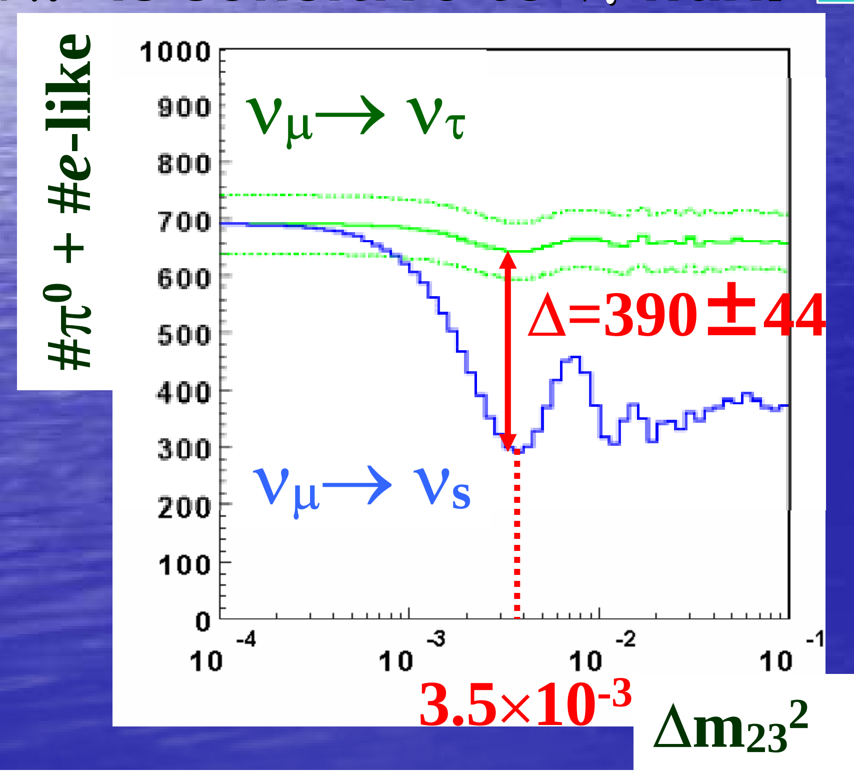
$\delta \sin^2 2\theta_{23} \sim 0.01$

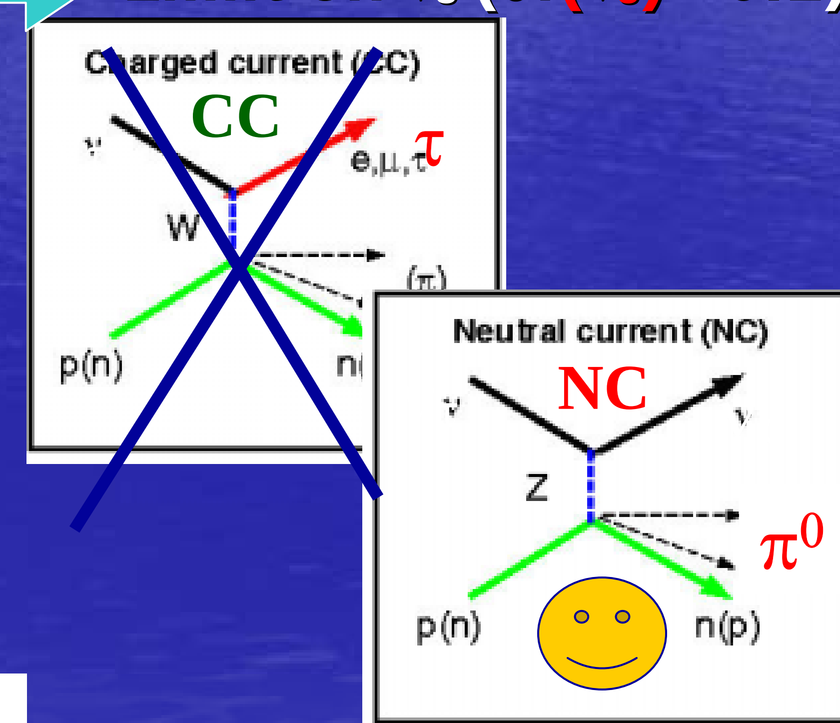
$\delta \Delta m_{23}^2 \quad < 1 \times 10^{-4} eV^2$

$\nu_\mu \rightarrow \nu_\tau$ confirmation w/ NC interaction

- NC π^0 interaction (ν + N → ν + N + π^0)
  - $\nu_\mu \rightarrow \nu_e$ CC + NC(~0.5CC) ~0 ($\sin^2 2\theta_{13}$~0)
    - $\rightarrow \nu_\mu$ CC + NC(~0.5CC) ~0 (maximum oscillation)
    - $\rightarrow \nu_\tau$ NC

#π^0 is sensitive to ν_τ flux. ➡ **Limit on ν_s ($\delta f(\nu_s)$~0.1)**





T2K ν oscillation probability
(Consider the difference from a reactor measurement)

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \Phi_{31}$$ θ13

$$+8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cos\Phi_{32} \sin\Phi_{31} \sin\Phi_{21}$$ CP conserving

$$-8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \sin\Phi_{32} \sin\Phi_{31} \sin\Phi_{21}$$ ~~CP~~

$$+4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos\delta) \sin^2 \Phi_{21}$$ solar ν

$$-8C_{13}^2 S_{13}^2 S_{23}^2 (1 - 2S_{13}^2) \frac{aL}{4E} \cos\Phi_{32} \sin\Phi_{31}$$ matter effect

$\Phi_{ij} = \Delta m_{ij}^2 L / 4E$, $S_{ij} = \sin\theta_{ij}$, $C_{ij} = \cos\theta_{ij}$

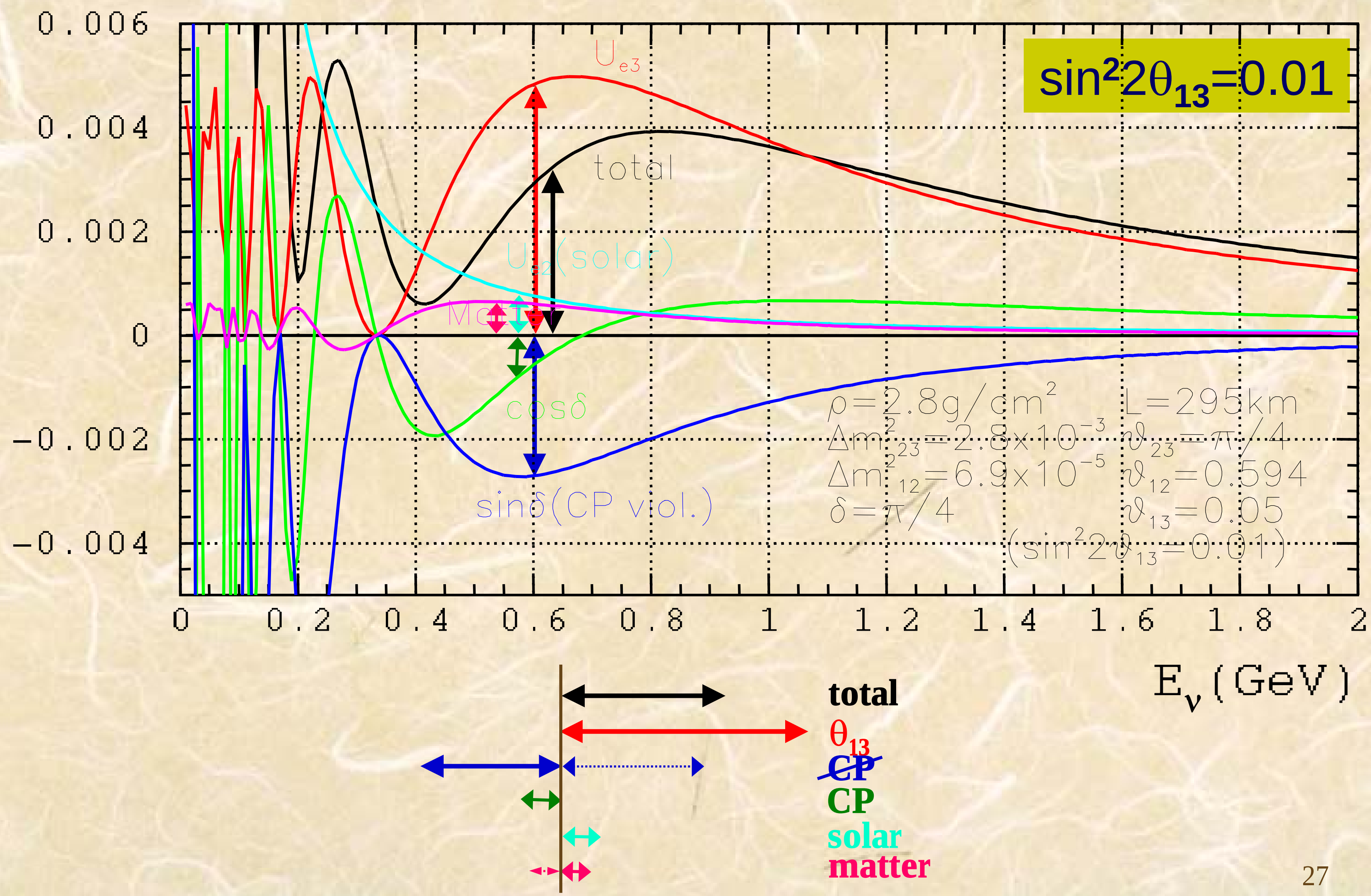
L : flight length, E : neutrino energy,

$\Delta m_{ij}^2 \equiv m_i^2 - m_j^2$, m_i : mass eigenvalues

$$a = 7.6 \times \left(\frac{\rho}{[g/cm^3]}\right)\left(\frac{E}{[GeV]}\right) \ [\mathrm{eV}^2]$$

$\delta \to -\delta$, a $\to$ -a for $\bar{\nu}_\mu \to \bar{\nu}_e$

$\nu_\mu \rightarrow \nu_e$ oscillation probability in T2K



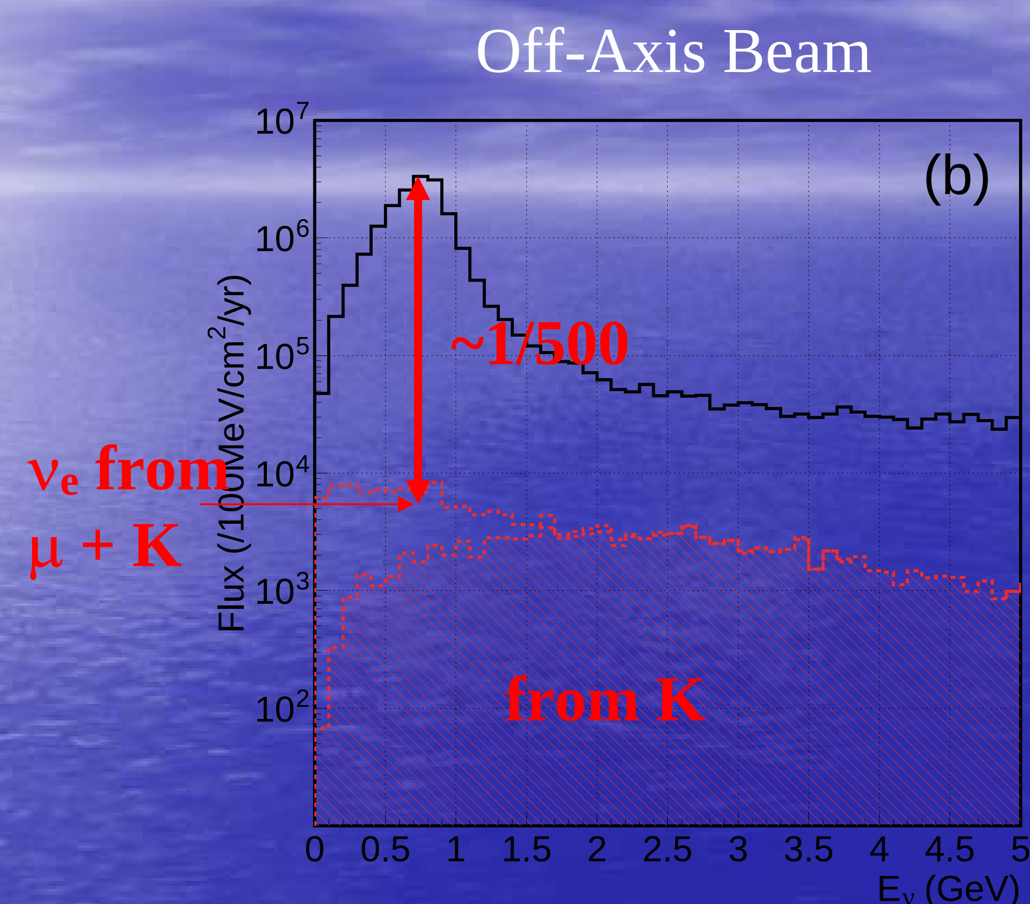
Summary

- Precision study of neutrino oscillation
  - Next step after the discovery
  - We may find a hint for next break-through.

- J-PARC neutrino experiment (2008~)
  - J-PARC 50GeV-PS+Off Axis beam+Super-K
  - Narrow band beam at the oscillation maximum (~ 1GeV)
  - ν_e appearance, discovery of θ_{13} (sin θ_{13}>0.006,90%CL)

Supplement

ν_e contamination in the beam



Intrinsic background: ν_e / ν_μ (peak) ~ 0.002