ICEPP Symposium @Hakuba
Feb 21st 2005

Current status of T2K experiment

1. Introduction
2. T2K experiment
3. Near neutrino detector
4. Summary

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Introduction

Next goal of neutrino experiments…

To explore the neutrino oscillation phenomena beyond the discovery phase

Mixing parameters

3 mass state(2mass difference)

Δm_{12}^2 : Solar ν & Reactor experiments 7~8 x $10^{-5}eV^2$

Δm_{23}^2 : Atm. ν & Long BaseLine experiments 2~3 x $10^{-3}eV^2$

3 mixing angles & 1 CPV phase

Maki-Nakagawa-Sakata Matrix (U_{ij})

$|\nu_\alpha\rangle = \Sigma U_{\alpha i} |\nu_i\rangle$

Weak — Mass eigenstates

$$U = \begin{bmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{bmatrix}$$

Long baseline experiments

$$= \begin{bmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & e^{-i\delta} \end{bmatrix} \begin{bmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{bmatrix}$$

(Solar + Reactor) $\sin^2\theta$=0.2-0.3

(Atm. ν) $\sin^2 2\theta$~1(>0.9)

(Reactor) $\sin^2 2\theta$<0.1~0.2

Remaining questions

- How close θ_{23} to $\pi/4$?

  Atmospheric neutrino measurements

  $\sin^2 2\theta > 0.9$ (Best fit $\sin^2 2\theta \sim 1$, $\Delta m^2 = 2\sim3 \times 10^{-3}$eV^2)

  Precise measurement of θ_{23} and Δm^2_{23}

- How large is 1st – 3rd generation mixing?

  Reactor experiment $\theta_{13} > 0$ or $\theta_{13} = 0$?

  $\sin^2 2\theta < 0.1\sim0.2$ @ $\Delta m^2 \sim 2.5 \times 10^{-3}$eV^2)

  Measurement of θ_{13}

- How large is the phase δ?

  Search for the CP violation

- Mass Hierarchy?
- Does sterile neutrino exist?
- ………

T2K(Tokai to Kamioka) long baseline neutrino oscillation experiment

Approved in Dec.2003

Conventional ν_μ beam

0.75MW beam (1st phase)

Baseline ~ 295km

Beam energy ~ 1GeV

Will be adjusted to the oscillation maximum

	Beam power	Far detector	Physics
1st phase	0.75MW	Super Kamiokande(50kt)	ν_μ disappearance ν_e appearance NC measurements
2nd phase	~4MW	Hyper Kamiokande(1Mt)	CP violation Proton decay

T2K collaboration

- Japan

KEK, ICRR, U. Tokyo, Tohoku U., Hiroshima U., Kyoto U., Kobe U., Osaka City U., Miyagi U. of Education

- USA

UCI, SUNY-SB, U. Rochester, U. Pennsylvania, Boston U., CSU, Duke U., Dominguez Hills, BNL, UCB/LBL, U. Hawaii, ANL, MIT, LSU, LANL, U. Washington

- Korea

Seoul National U., Chonnam National U., Dongshin U., kangwon U., Kyungpook National U., KyuSang National U., SungKyunKwan U., Yonsei U.

- Poland

Warsaw U.

- Spain

U. Barcelona, U. Valencia

- Switzerland

U. Geneva

- Russia

INR

- Italy

U. Roma, U. Bari, U. Napoli, U.Padova

- France

CEA Saclay

- Canada

TRIUMF, U. Alberta, York U., U. Toronto, U. Victoria, U. Regina

- China

IHEP (Inst. of High Energy Phys.)

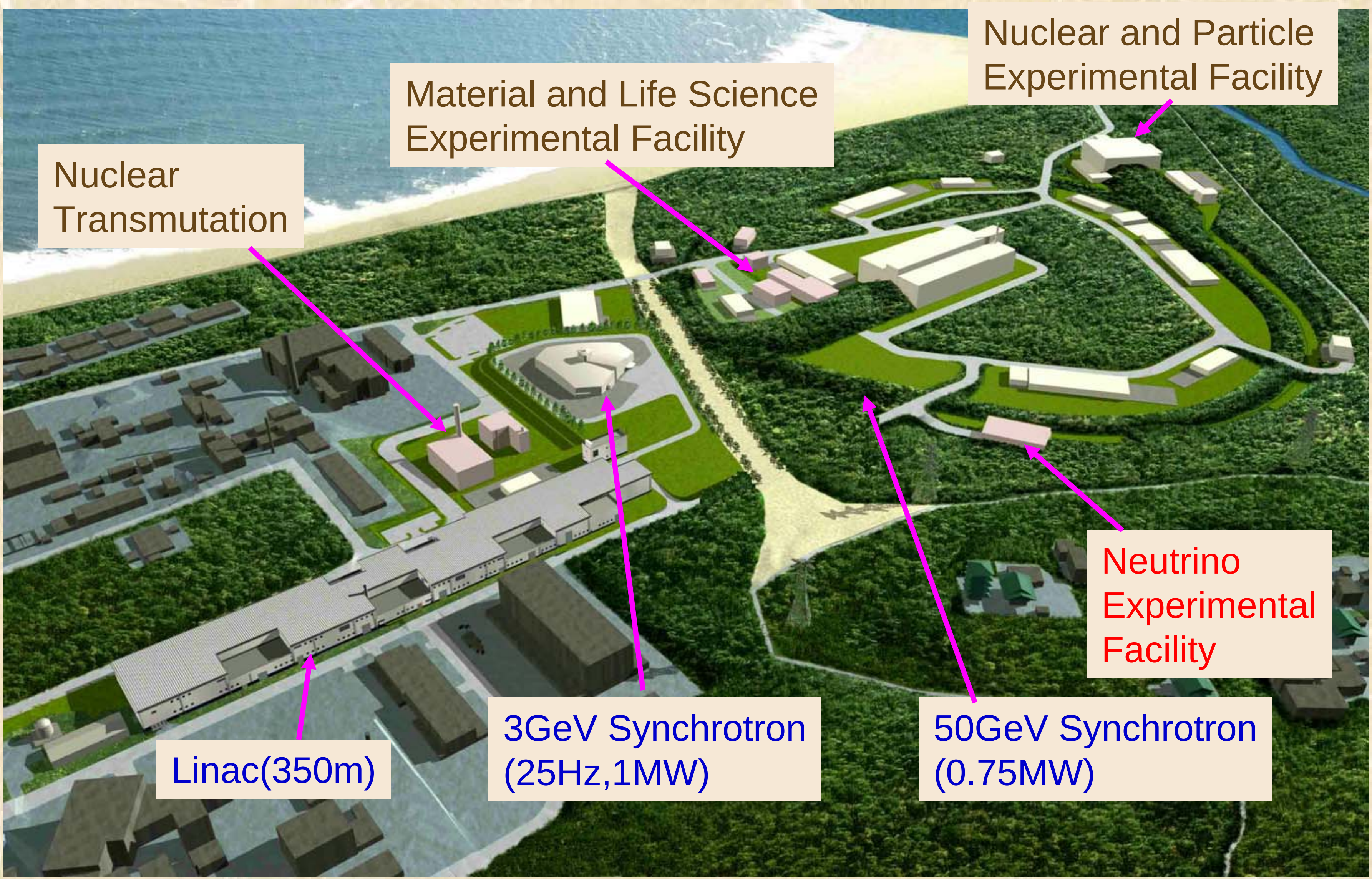
- UK

RAL, Imperial College London, Queen Mary Westfield College London, U. Liverpool

- Formed in May 2003
- 12 countries, 53 institutions
- ~150 collaborators (not incl. students)

J-PARC overview

J-PARC=Japan Proton Accelerator Research Complex



Construction status

Apr. 2001: J-PARC Phase 1 construction was started
Dec.2003: Neutrino experiment was approved!

3GeV Synchrotron (Jan 05)

50GeV Synchrotron (Jan 05)

LINAC (Nov 04)

In 2008, accelerator will be in operation.
Start ν experiment physics run in 2009!

Neutrino beam line

Proton beam kinetic energy

50GeV (40GeV@T=0)

# of protons / pulse

3.3×10^{14}

Beam power

750kW

Bunch structure

8 bunches

Bunch length (full width)

58ns

Bunch spacing

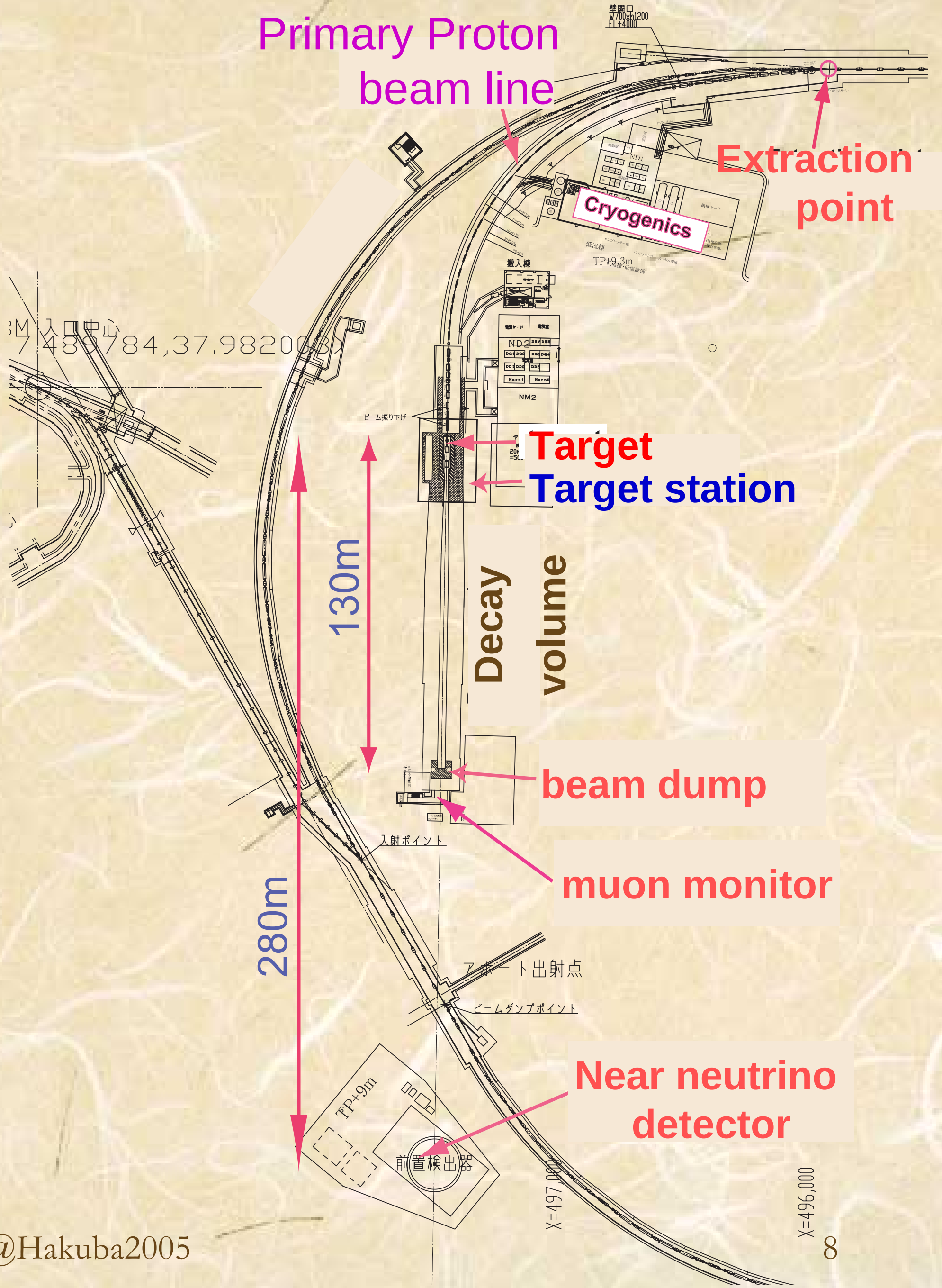
598ns

Spill width

~5μs

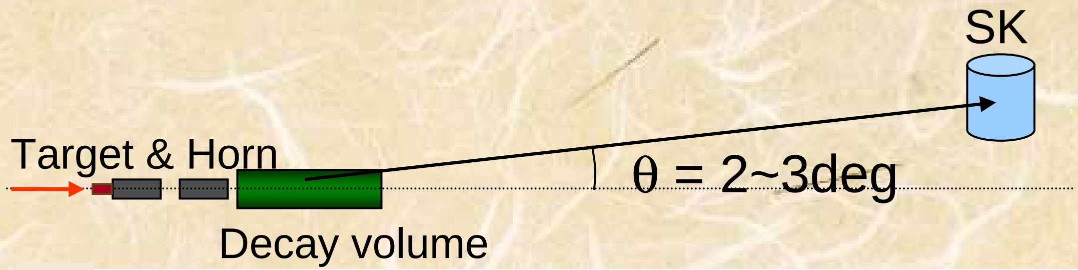
Cycle

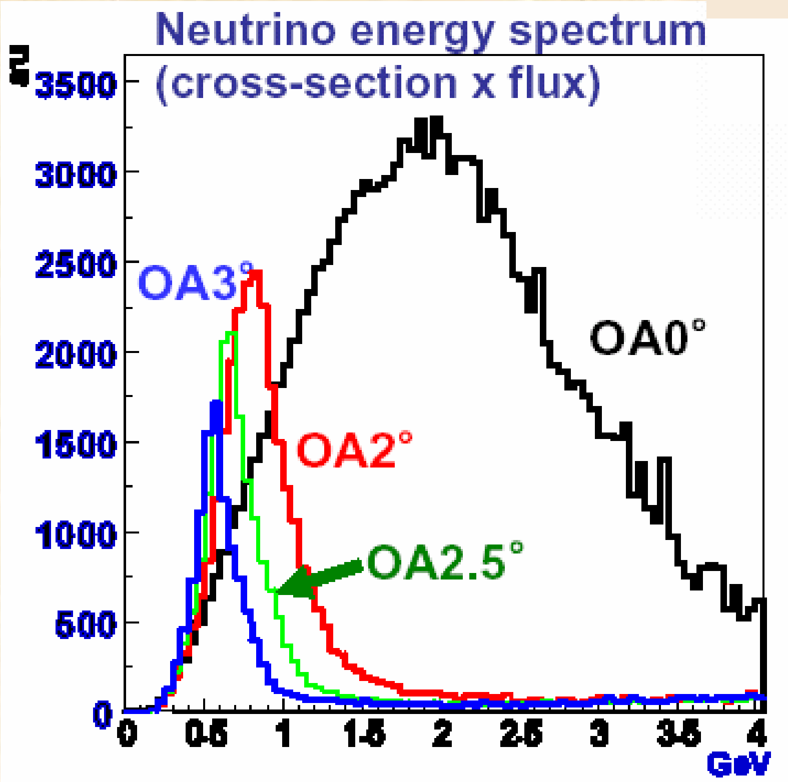
3.53sec

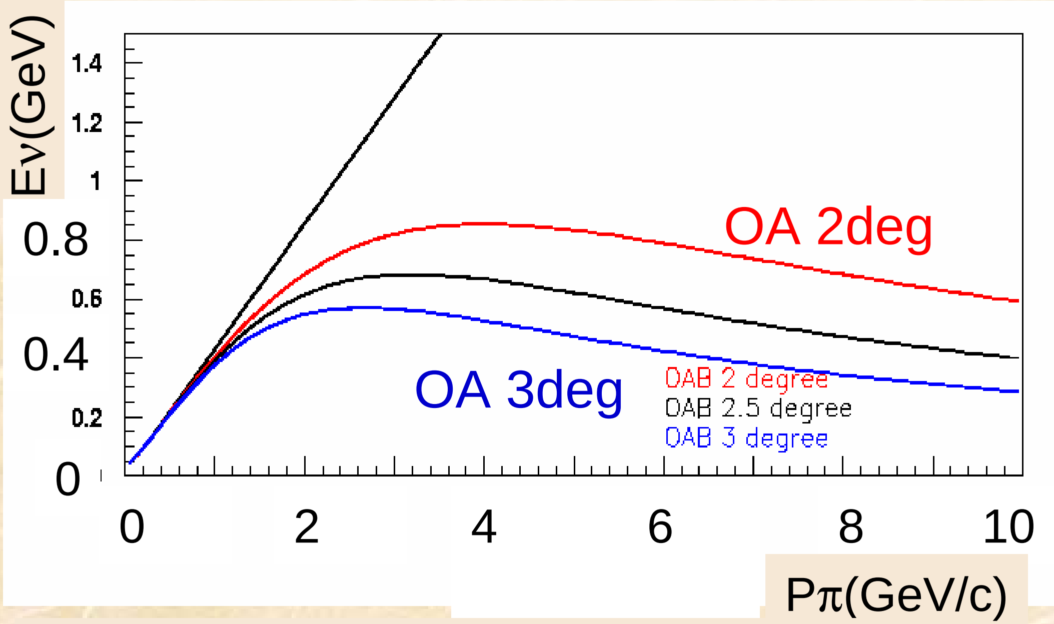


Off-axis beam(2-3deg) (Ref.;BNL-E889 proposal: http://minos.phy.bnl.gov/nwg/papers/E889)

- Quasi-monochromatic beam
- Beam energy is tunable to maximize the sensitibity!





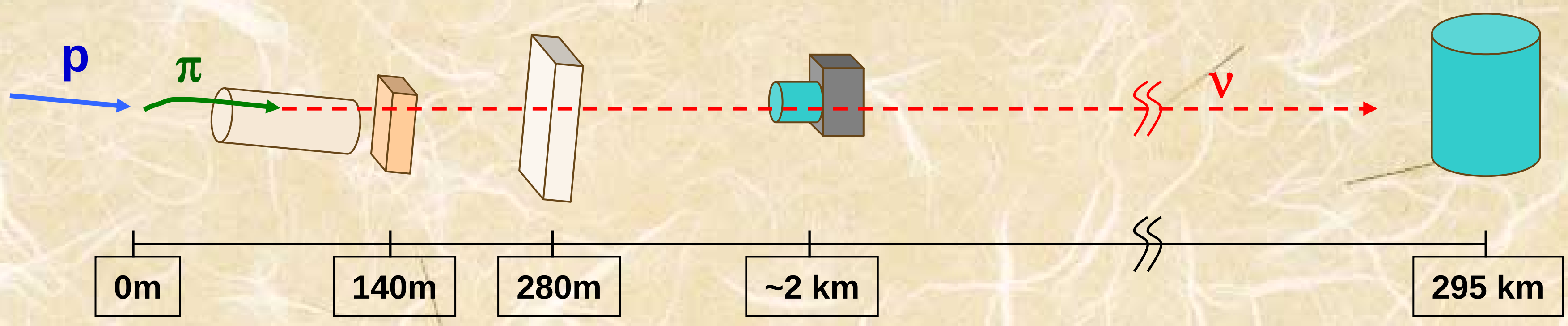


Expected # of interactions @ SK
(OA 2deg)

ν_μ	total	: ~4500/22.5kt/yr
	CC	: ~3000/22.5kt/yr

ν_e ~0.2% at ν_μ peak

Schematic view of the detectors



Muon monitor @ ~140m

- First (spill-by-spill) monitoring of beam direction & intensity

First Front Detector @ 280m

- Neutrino energy spectrum, intensity and direction
- Study neutrino interaction

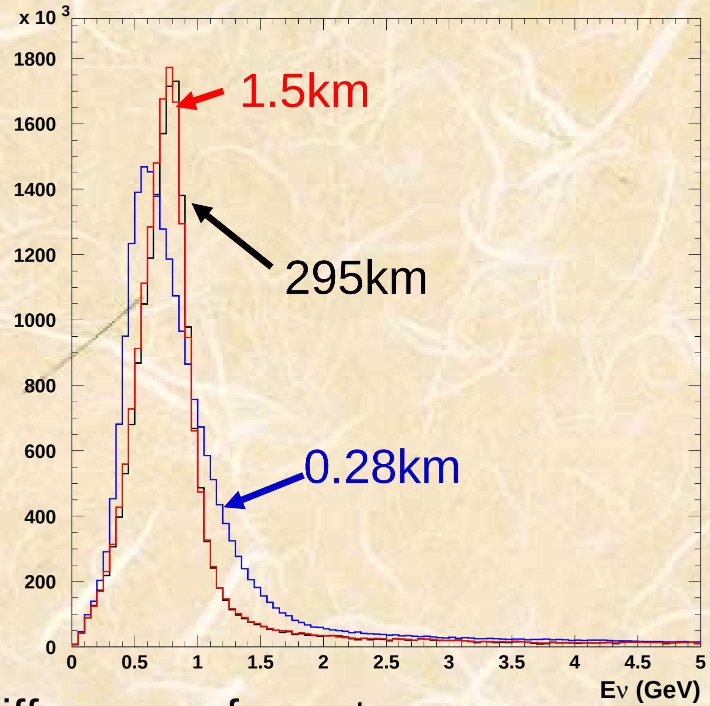
(Second Front Detector @ ~2km)

- Almost same Eν spectrum as for SK

Far Detector @ 295km

- Super-Kamiokande(50kt)

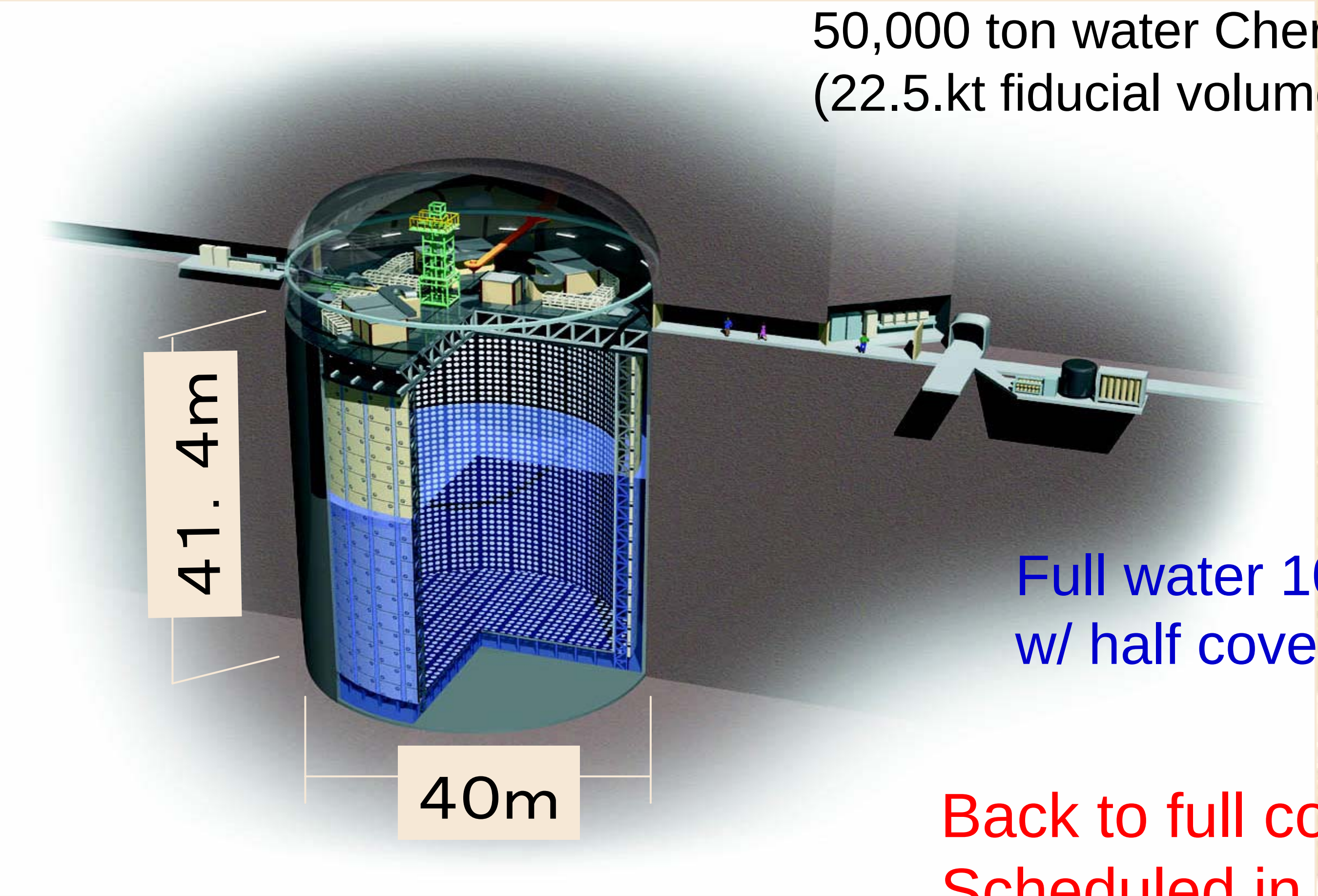
Neutrino spectra at different distance



Difference of spectra

⇨ Dominant systematic error in K2K

Far detector
Super-Kamiokande



50,000 ton water Cherenkov detector
(22.5.kt fiducial volume)

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

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

Physics Goal at the 1st phase(5yrs)

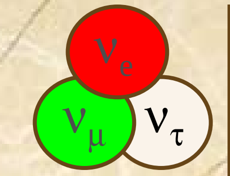
- Precise measurement of neutrino mixing matrix
  ν_μ disappearance ($\nu_\mu \rightarrow \nu_x$)

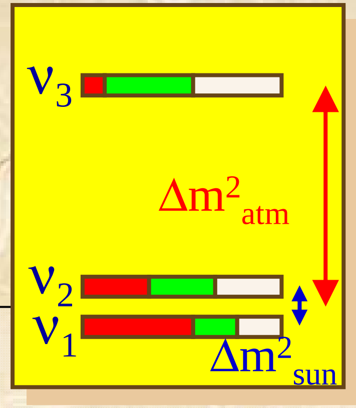
  Accuracy: $\sin^2 2\theta_{23}$......1%
  Δm^2_{23}……a few %(< 1×10^{-4} eV^2)

- Discovery and measurement of non-zero θ_{13}
  ν_e appearance ($\nu_\mu \rightarrow \nu_e$)

  $\sin^2 2\theta_{13}$......> 0.006
  1st evidence of 3-flavor mixing!
  1st step of 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**

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

~1

common

- θ_{13}: ν_e **appearance**

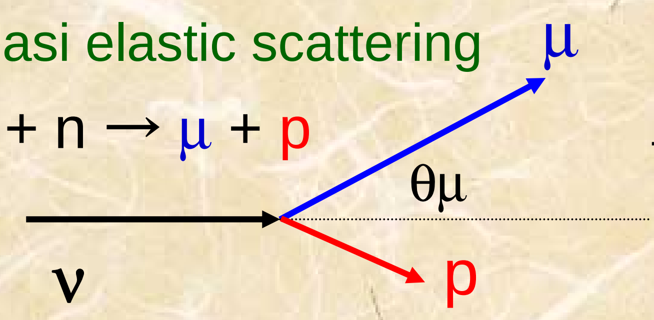
$$P_{\mu \to e} \approx \sin^2 \theta_{23} \cdot \sin^2 2\theta_{13} \cdot \sin^2 \left(1.27 \Delta m^2_{23} L / E_\nu \right)$$

~0.5

How to reconstruct neutrino energy

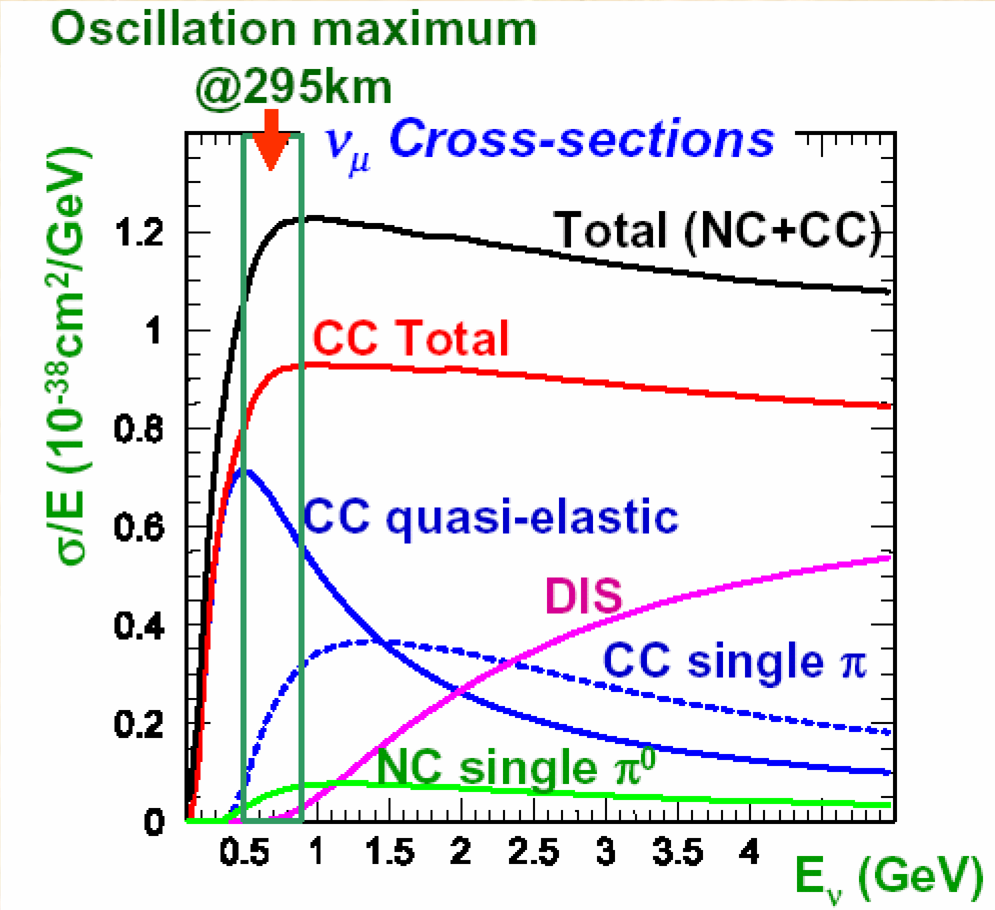
CC quasi elastic scattering

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



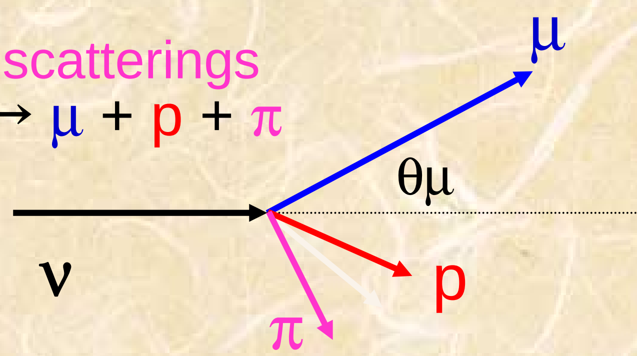
It is possible to reconstruct Eν from Pμ and θμ

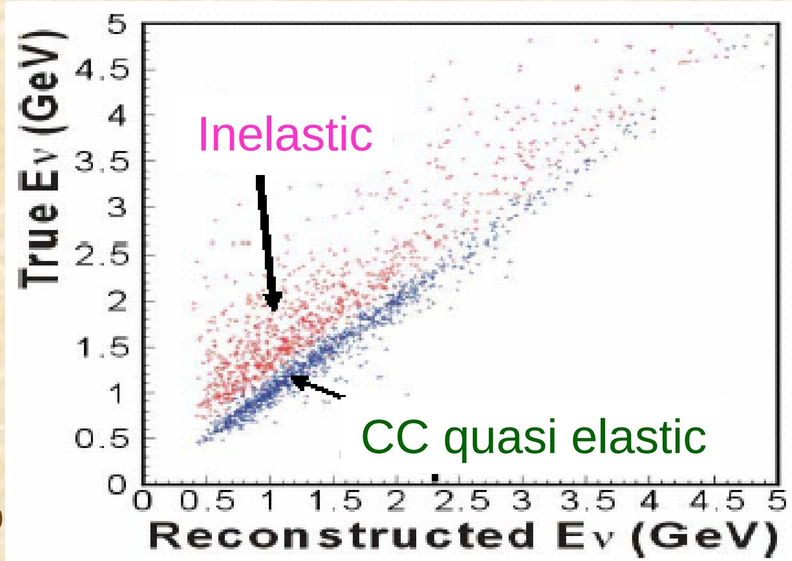
$$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$



Inelastic scatterings

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

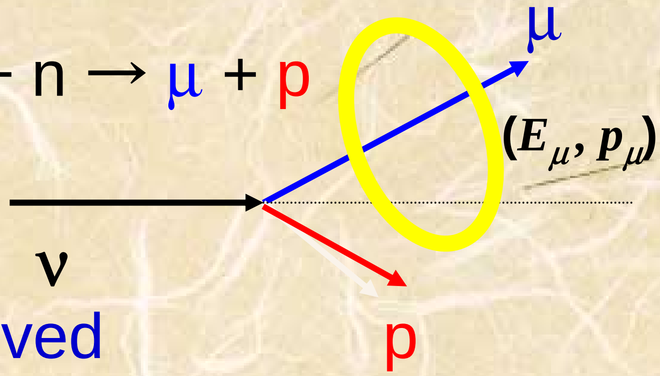




Measurement of θ_{23}, Δm_{23}^2

Use 1 ring μ-like events @ SK
(= quasi-elastic enriched sample)
to reconstruct neutrino energy

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

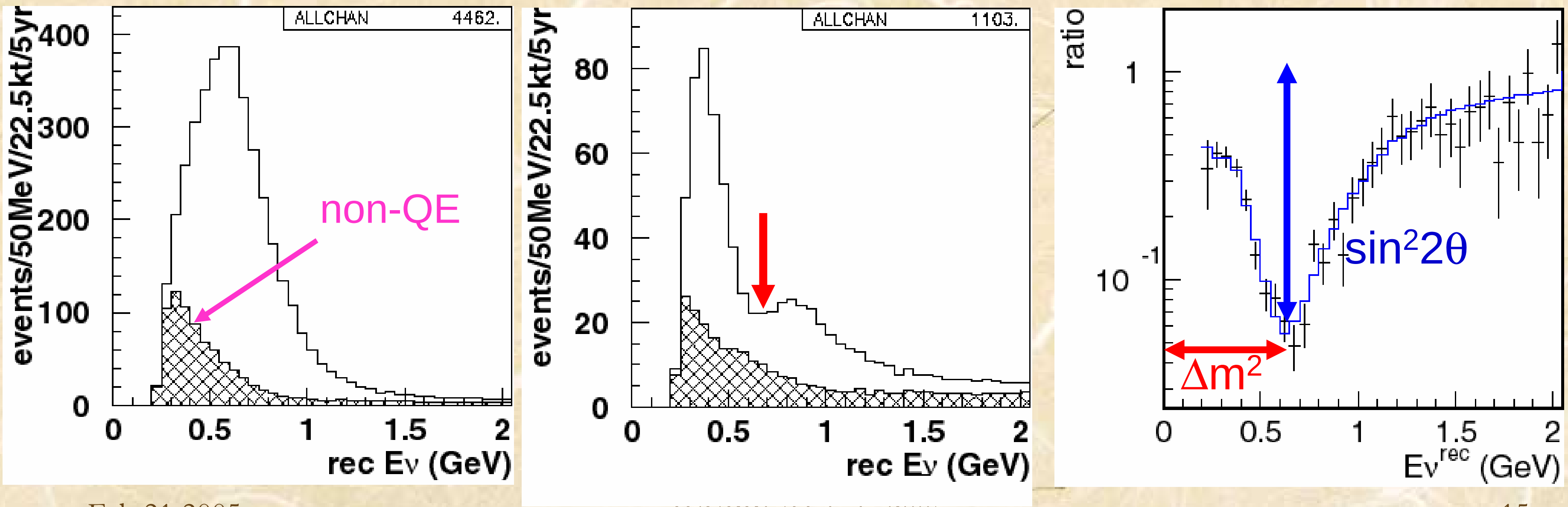


Clear deficit is expected to be observed in the reconstructed ν energy

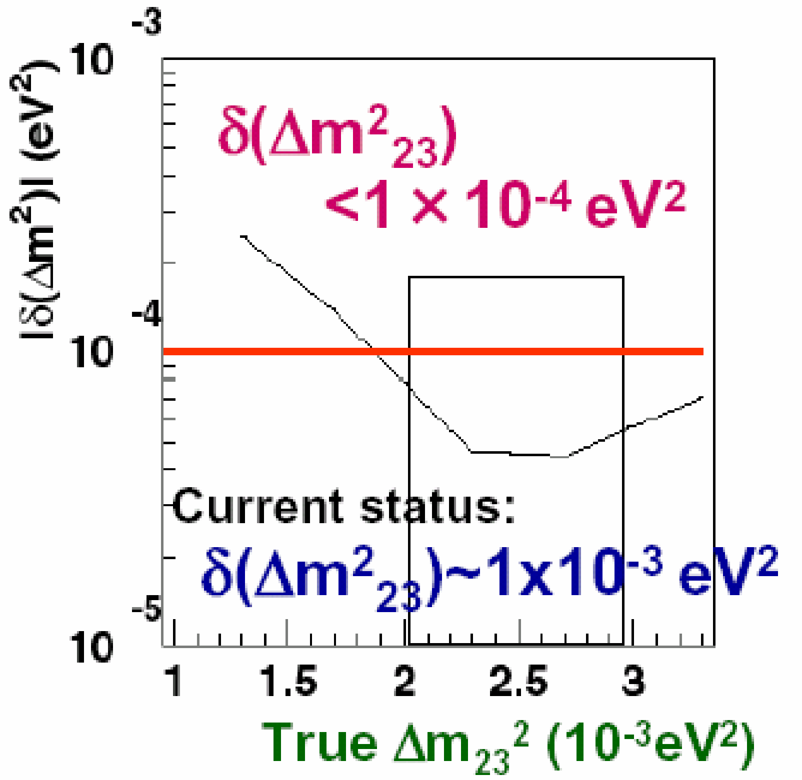
~OA 2.5deg ~

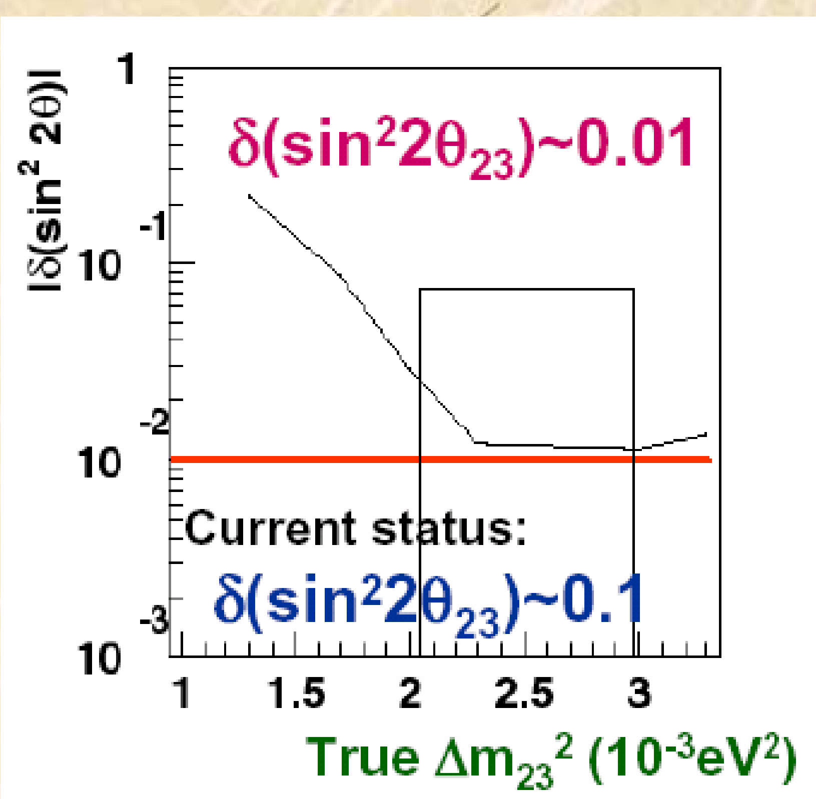
No oscillation

$\Delta m_{23}^2 = 2.7 \times 10^{-3} eV^2$
(assuming $\sin^2 2\theta_{23}=1.0$)



Measurement of θ_{23}, Δm_{23}^2





Sensitivities in the 1st phase

$\delta(\Delta m_{23}^2) < 1 \times 10^{-4}$ eV^2
$\delta(\sin^2 2\theta_{23}) \sim 0.01$

ν_e appearance search

θ_{13} measurement

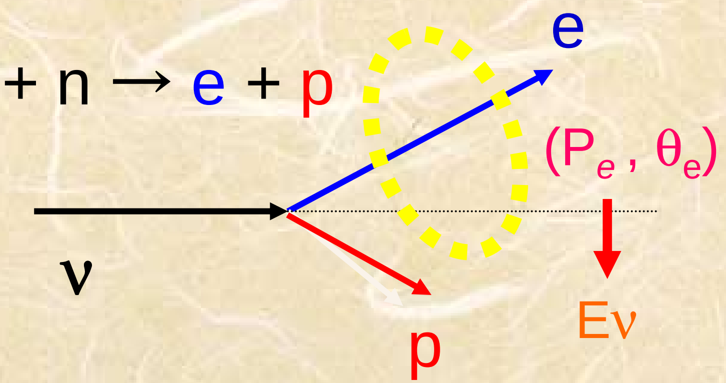
$$P_{\mu\to e} \approx \sin^2\theta_{23}\cdot\sin^2 2\theta_{13}\cdot\sin^2\left(1.27\Delta m_{23}^2 L/E_\nu\right)$$

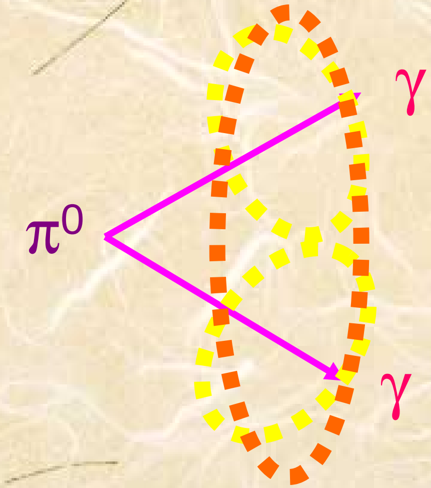
Upper limit: $\sin^2\theta_{13} < 0.03 \sim 0.05$ (@$\Delta m^2 = 2\sim3 \times 10^{-3}$eV^2)

- Signal events @ SK
  single ring e-like event
  (ν_e CC quasi-elastic scattering)

- Possible background sources
  1) Beam ν_e
     ν_e/ν_μ flux ~ 0.2%(@peak)
  2) π^0 production
     2-ring merged to 1-ring

$\nu_e + n \rightarrow e + p$





ν_e appearance search

Expected # of background

Event selection

- Select 1ring e-like events
- Apply π^0 rejection cut
- Energy cut (around the oscillation maximum)

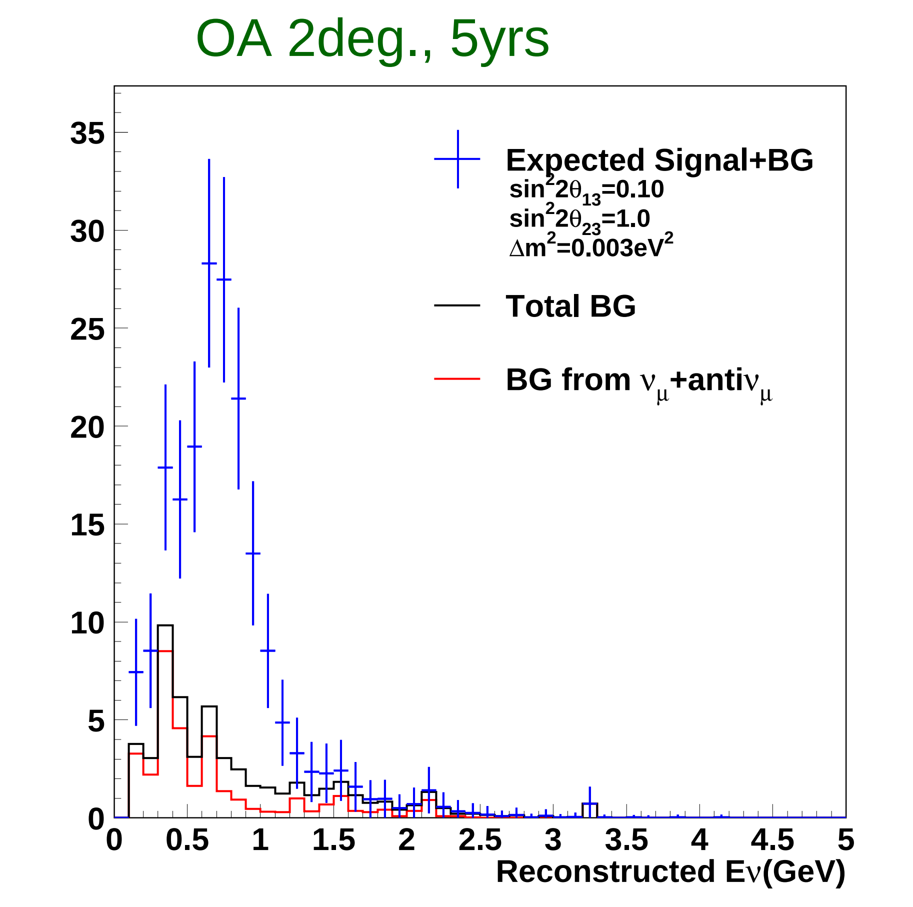
Assuming $\sin^2 2\theta_{23}=1.0$, $\Delta m_{23}^2=2.7\times10^{-3}\text{eV}^2$

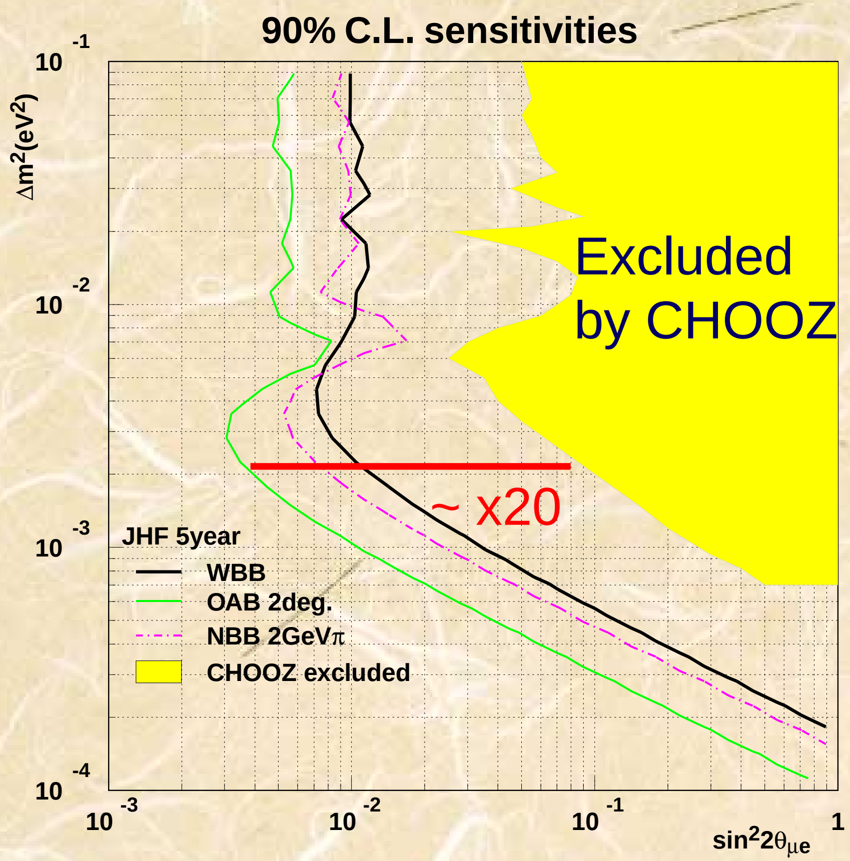
OA 2.5deg 5yrs	ν_μ CC (oscillated)	ν_μ NC			Beam ν_e
		$1\pi^0$	coherent	DIS	
1) Generated in FV	2,897	432	71	2,410	225
2) 1ring e-like	5.9	74	22	41	64
3) e/π^0 separate	0.8	14	2.6	4.3	26
4) $0.4\text{GeV}<E_\nu^{rec}<1.2\text{GeV}$	0.4	6.3	0.8	1.9	16

Sensitivities in the 1st phase(5yrs)

Search for ν_e appearance

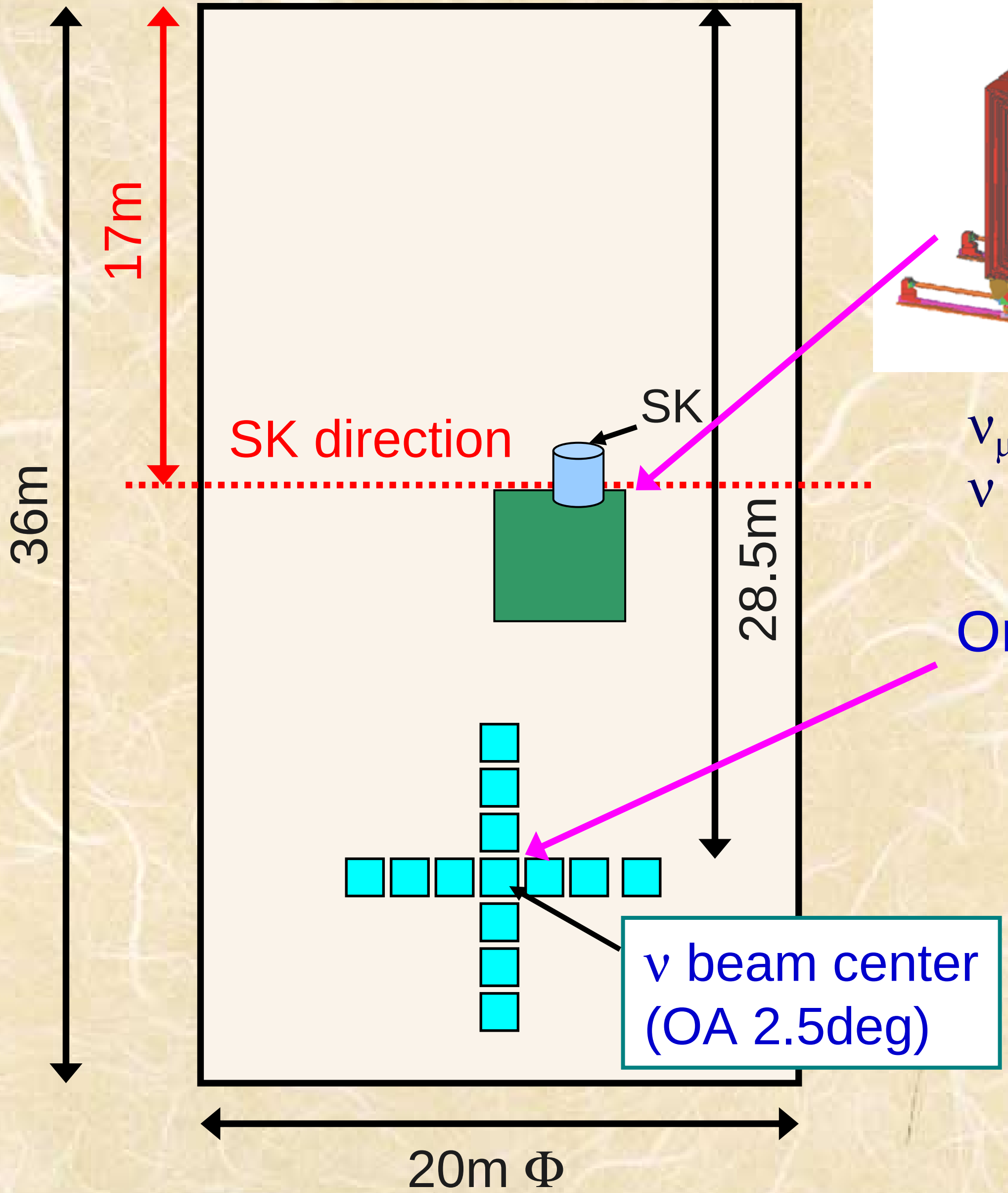
w/ beam MC and full SK detector simulation



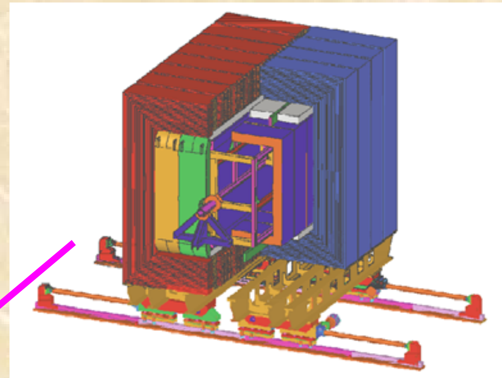


Sensitivity region…$\sin^2 2\theta_{13}>0.006(90\%)$
$\sin^2 2\theta_{13}>0.018(3\sigma)$

Near neutrino detector

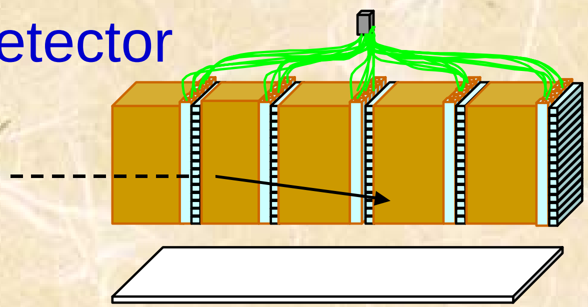


Off-axis detector (w/ magnet)



ν_μ and ν_e fluxes and energy spectra
ν interaction study

On-axis detector



Monitor ν beam

Off-axis detectors

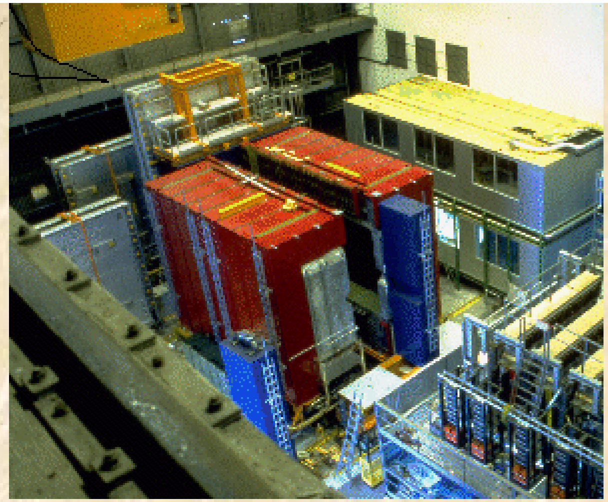
Tracking detector

-Fine Grained Detector consisting of scintillator

Target of ν

-TPC

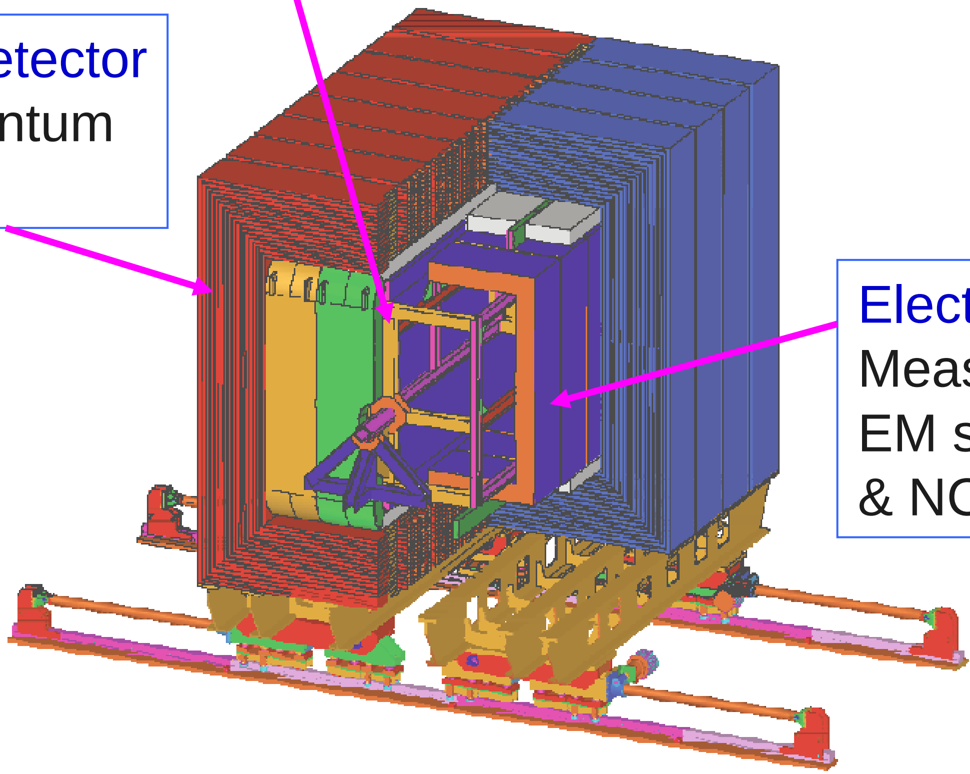
Measure momentum of μ, p and π



UA1 magnet @NOMAD experiment

Muon Range Detector

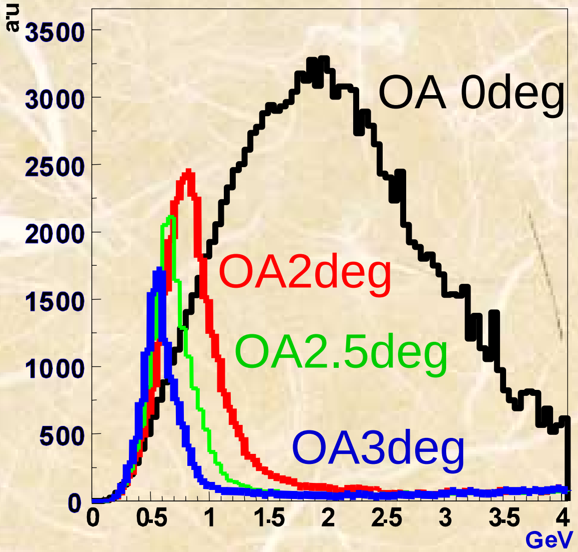
Measure momentum of μ



Electron calorimeter

Measure energy of EM shower by beam ν_e & NC-1π^0

On-axis detector



Uncertainly of energy scale

δ<Eν>/<Eν>~24MeV/mrad

→ $\delta(\Delta m^2)=10^{-4}eV^2/mrad$

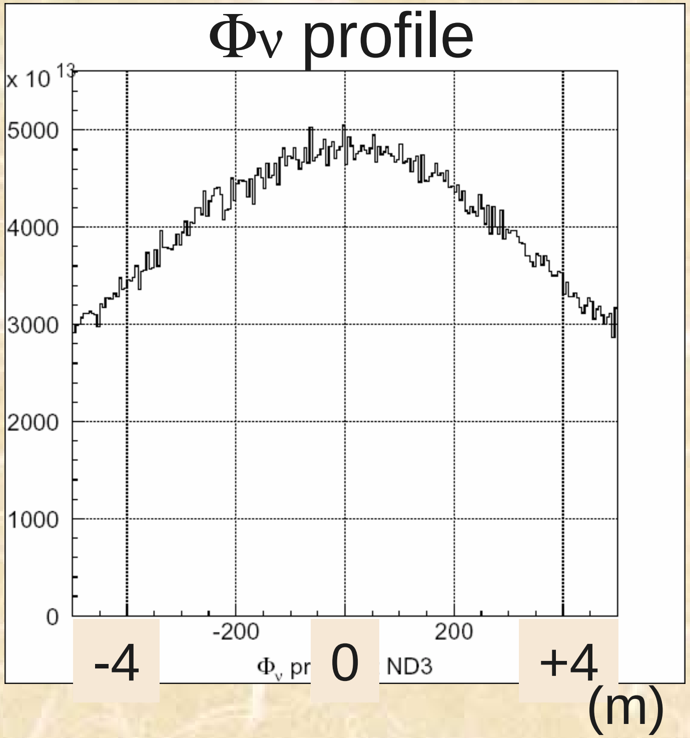
Oscillation probability

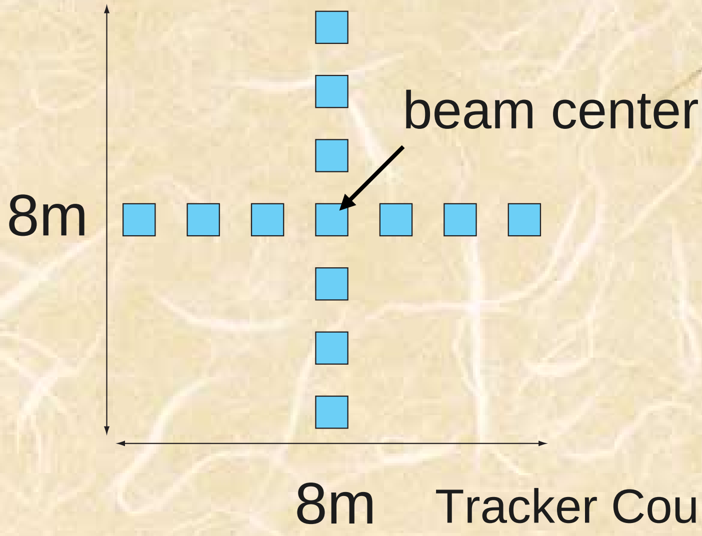
$$P(\nu_\alpha \to \nu_{\beta\neq\alpha}) = \sin^2 2\theta \sin^2(1.27\Delta m^2 \frac{L}{E_\nu})$$

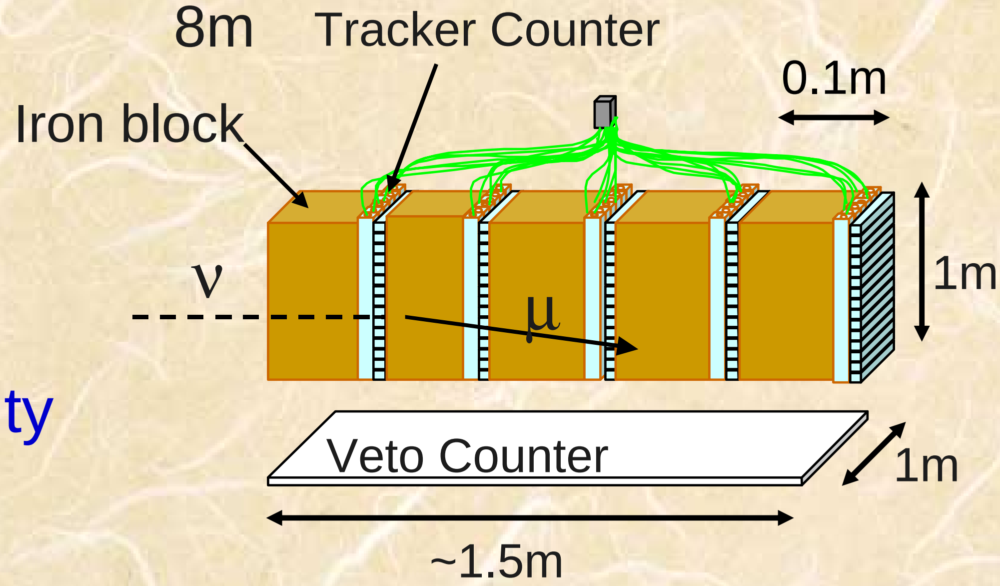
It's necessary to measure ν beam direction w/ high accuracy and control precisely

<u>At least 0.5mrad is needed as a measurement accuracy</u>

On-axis detector (N-Grid detector)



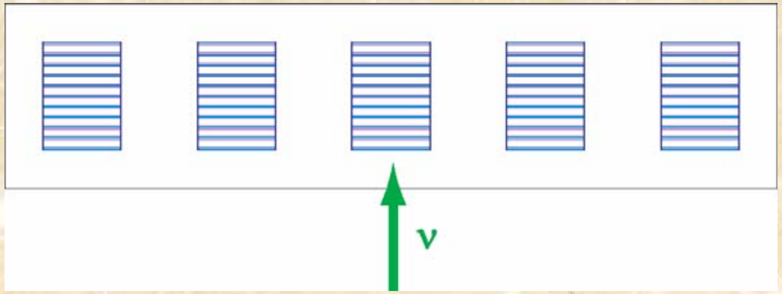


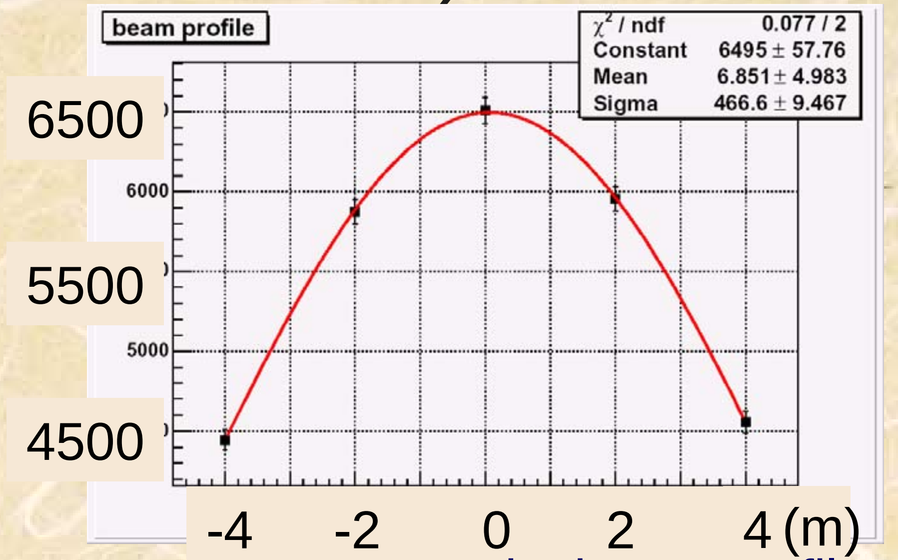


Monitor neutrino beam direction, profile and stability

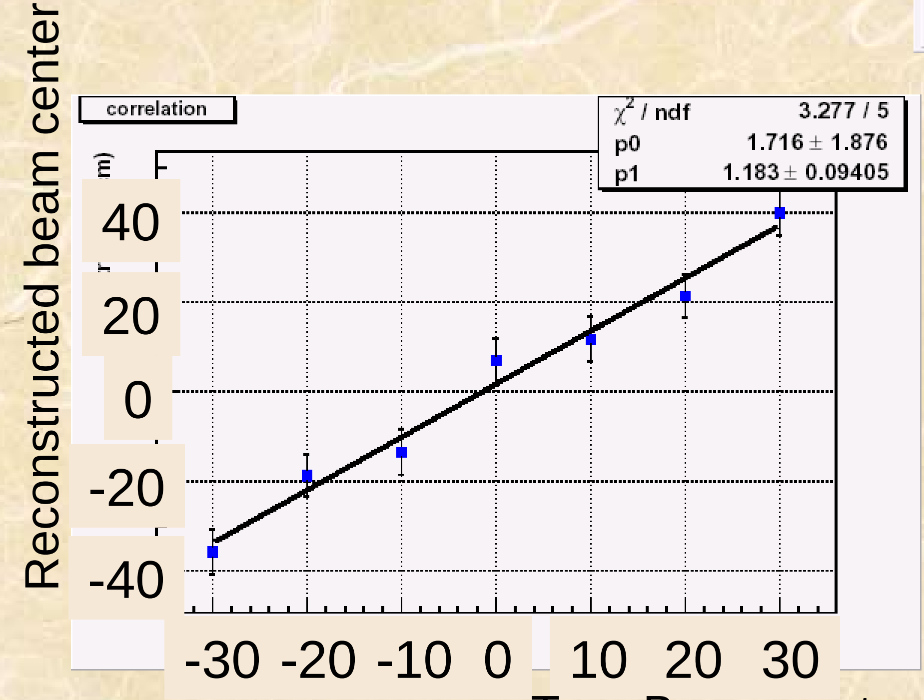
On-axis detector (N-Grid detector)

5 modules at one axis





Reconstructed ν beam profile



True Beam center

- Good linear relation.
- The accuracy of the center is ~5cm.

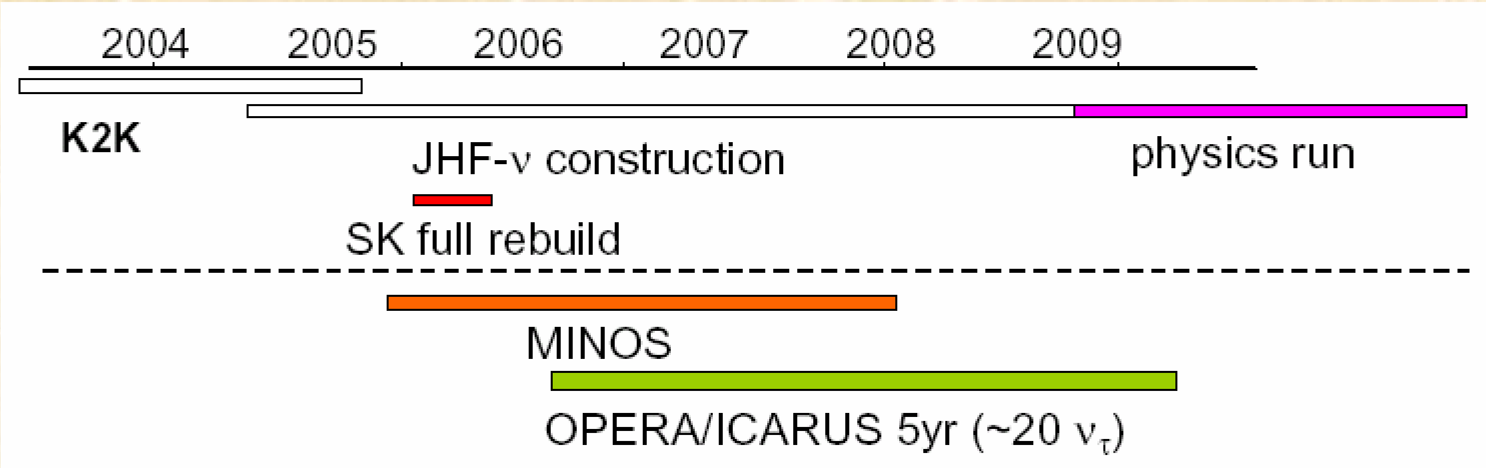
→corresponding to 0.18mard

<u>(fulfill the request)</u>

Summary

The first "Super-beam" Long baseline ν experiment
T2K (Tokai to Kamioka) experiment was approved

- Construction was started
- 5 years to complete (JFY 2004~2008)
- Start physics run in *2009*
  - Try to discover non-zero θ_{13} ($\sin^2 2\theta_{13}$>0.006 @90%C.L.)
  - Precision measurement of θ_{23} & Δm_{23}^2 (precision x 10)
  - 1st step to the CP violation in the lepton sector



Supplement

Tight e/π^0 separation

Shower direction from the beam axis

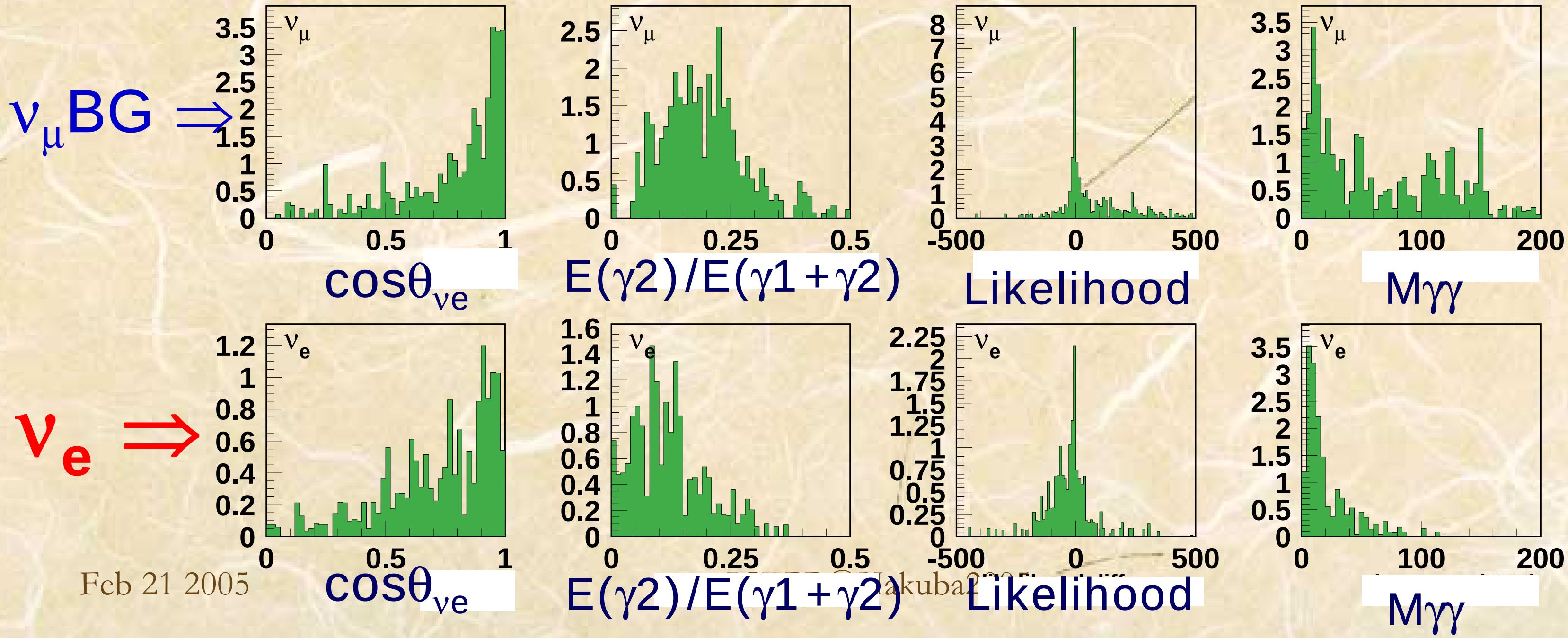
$\cos\theta_{\nu e}$: γ from coherent π^0 tends to have a forward peak

Force to find 2nd ring and…

E(γ2)/E(γ1+γ2): The second ring energy is larger for BG

Likelihood diff. between 1-ring and 2-rings

Invariant mass: Small for ν_e



N-Grid detector

Event Selection

[1] ≧2 hits in the scintillator.

[2] No Veto Hits

[1] & [2]