Future Accelerator-based Oscillation Experiment (JHFnu, Off-axis)

Changgen Yang
Institute of High Energy Physics
Beijing

Outline

- Introductory Comments
- Beam Option and Detector
- Physics Goals
- Present Schedule
- Concluding Remarks

Introductory Comments

The current generation of long and medium baseline ν oscillation experiments is designed to:

1. Confirm SuperK results with accelerator ν's (K2K)
2. Make precise measurement of oscillation parameters (JHFnu, MINOS)
3. $\nu_\mu \rightarrow \nu_e$ apperance search (JHFnu, MINOS)
4. $\nu_\mu \rightarrow \nu_\tau$ apperance search (OPERA, ICARUS)
5. Resolve the LSND puzzle (MiniBooNE)

Many issues in neutrino physics will still remain unresolved. Next generation experiments is needed.

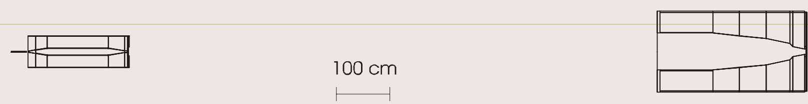
Beam Option:

- To maximize flux at the desired energy (near oscillation maximum)
- To minimize flux at other energies
- Have narrow energy spectrum
- Low background

Based on the knowledge of the dominant oscillation parameters

Three Beams

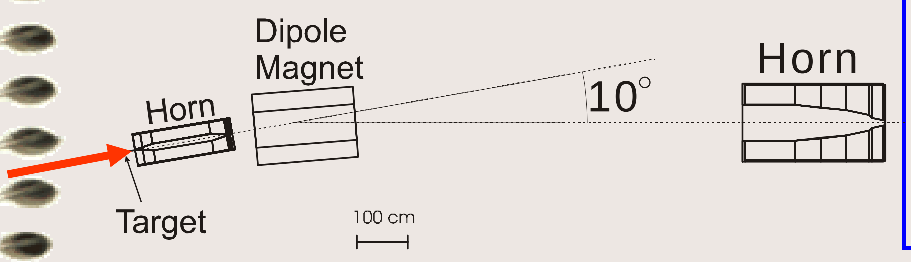
Wide Band Beam



2horns

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

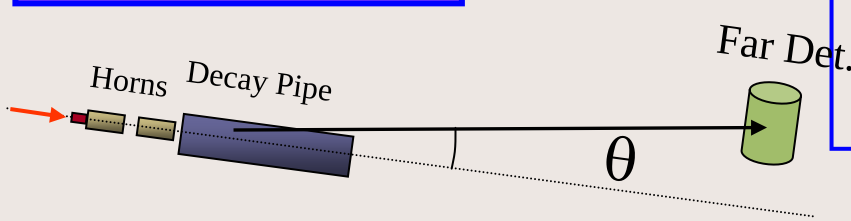
Narrow Band Beam



momentum selected π

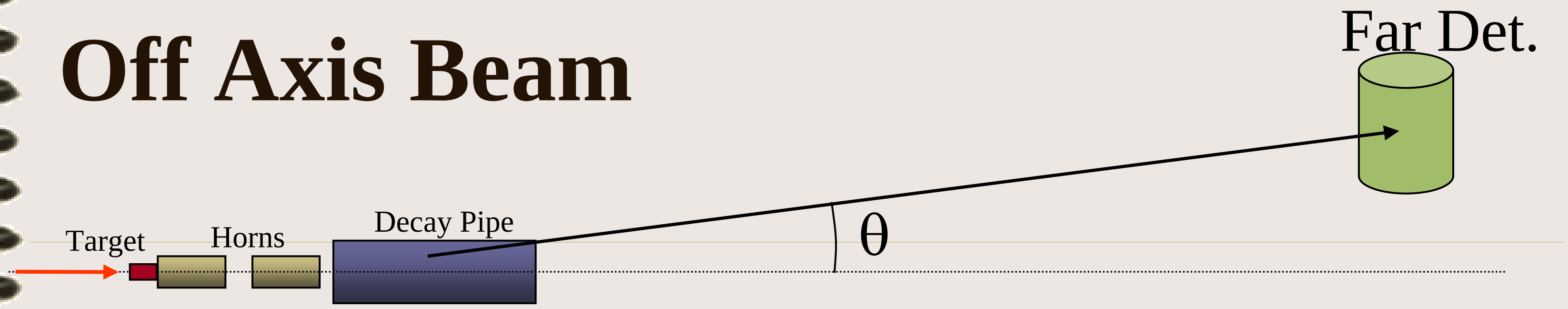
- Less HE tail
- Less sys err from spectrum "counting experiment"
- Easy to tune E_ν

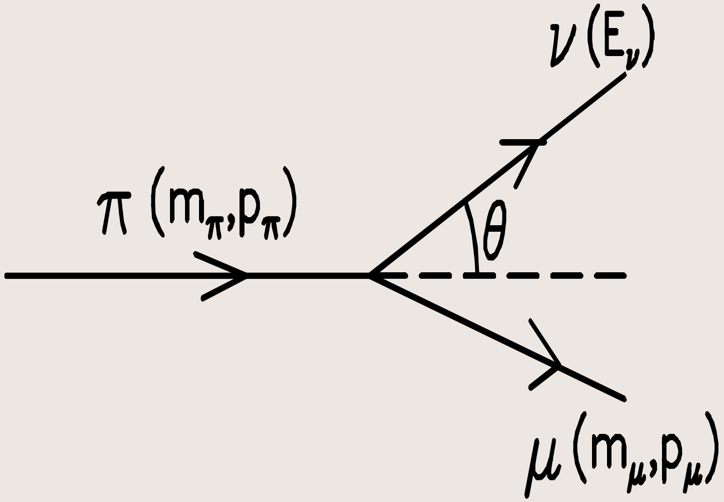
Off Axis Beam



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

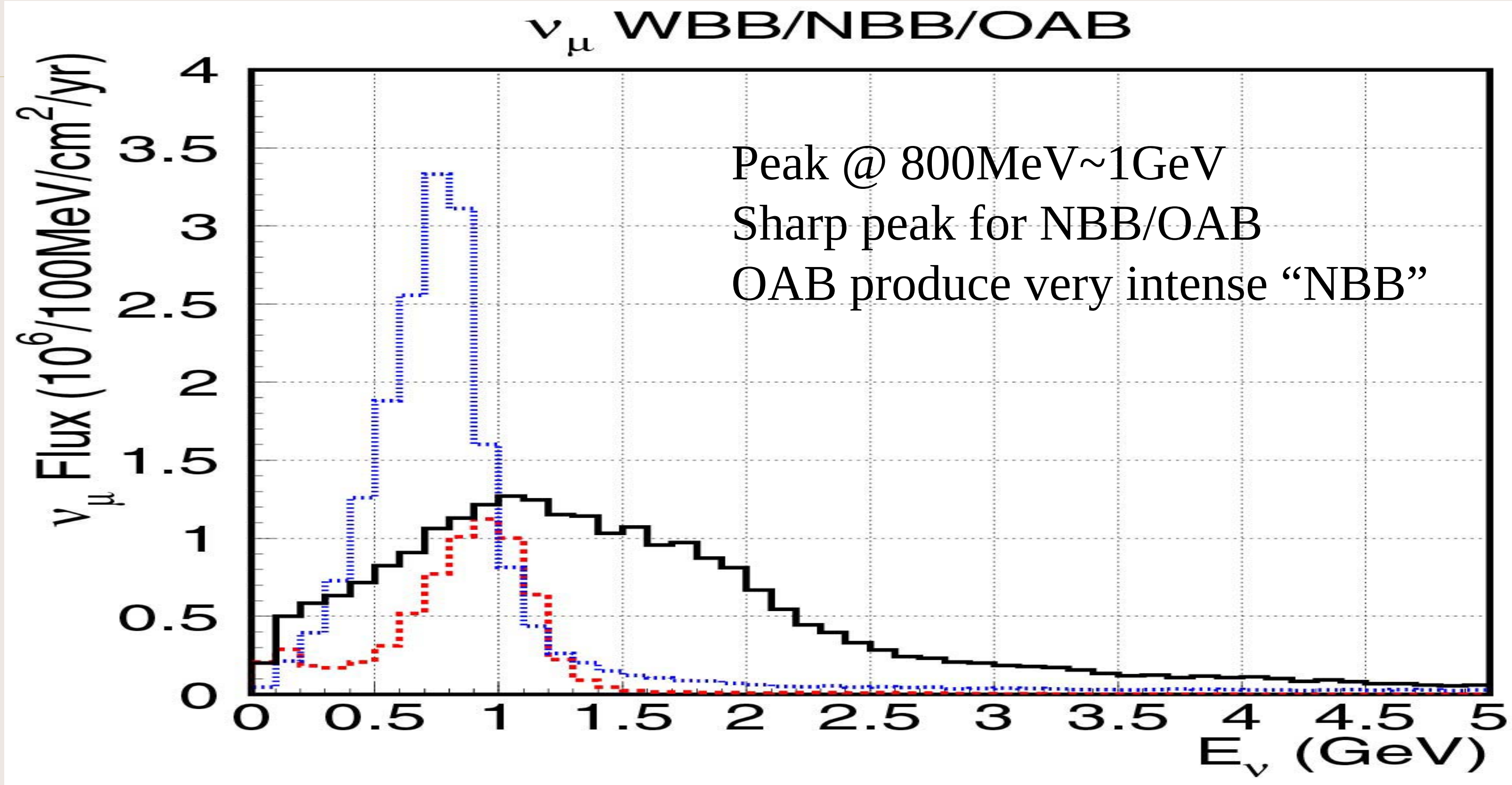
Off Axis Beam





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

Comparision of Spectra



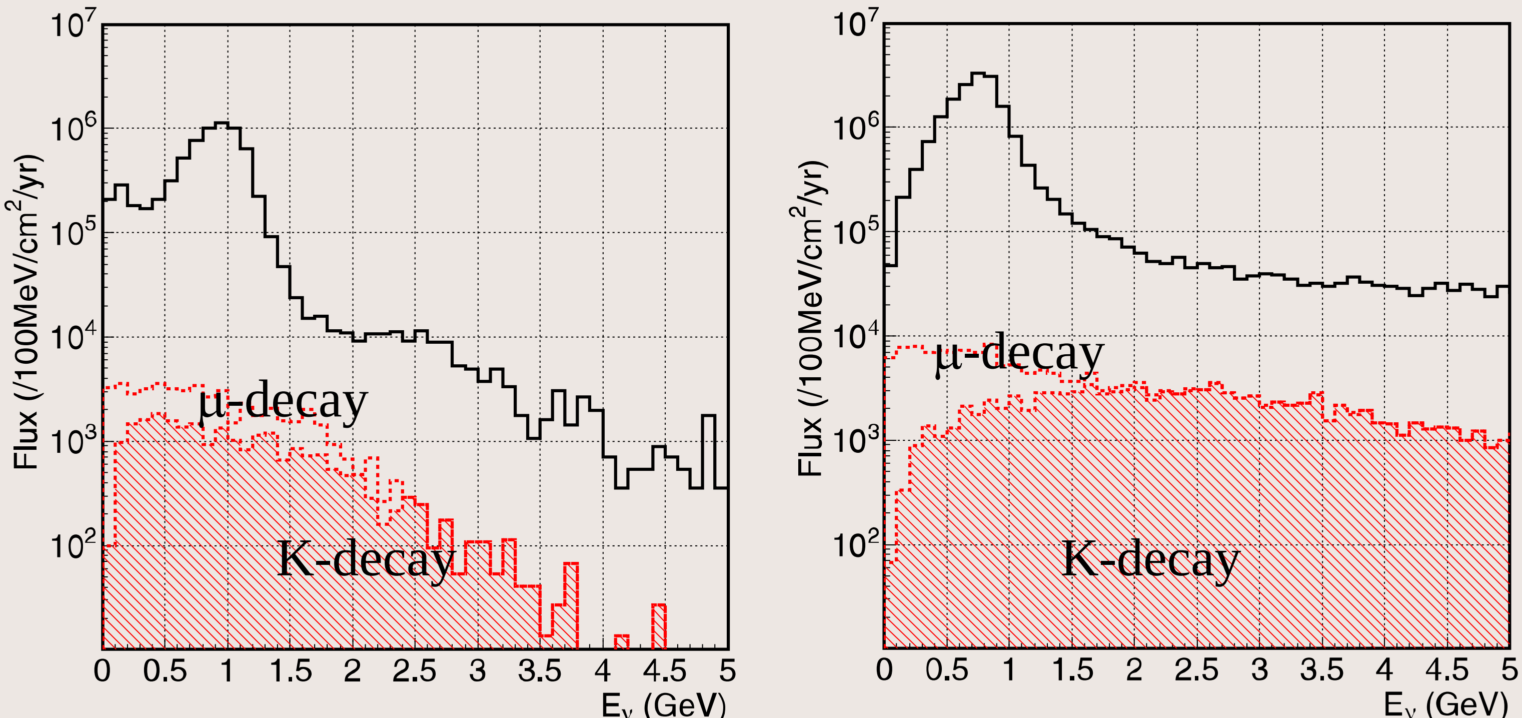
WBB:**5200** CC int./22.5kt/yr

NBB: **620** CC int./22.5kt/yr (2GeV/c π tune)

OAB: **2200** CC int./22.5kt/yr (2degree)

ν_e contamination

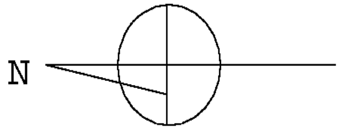
NBB (LE2π) | OAB (2degree)



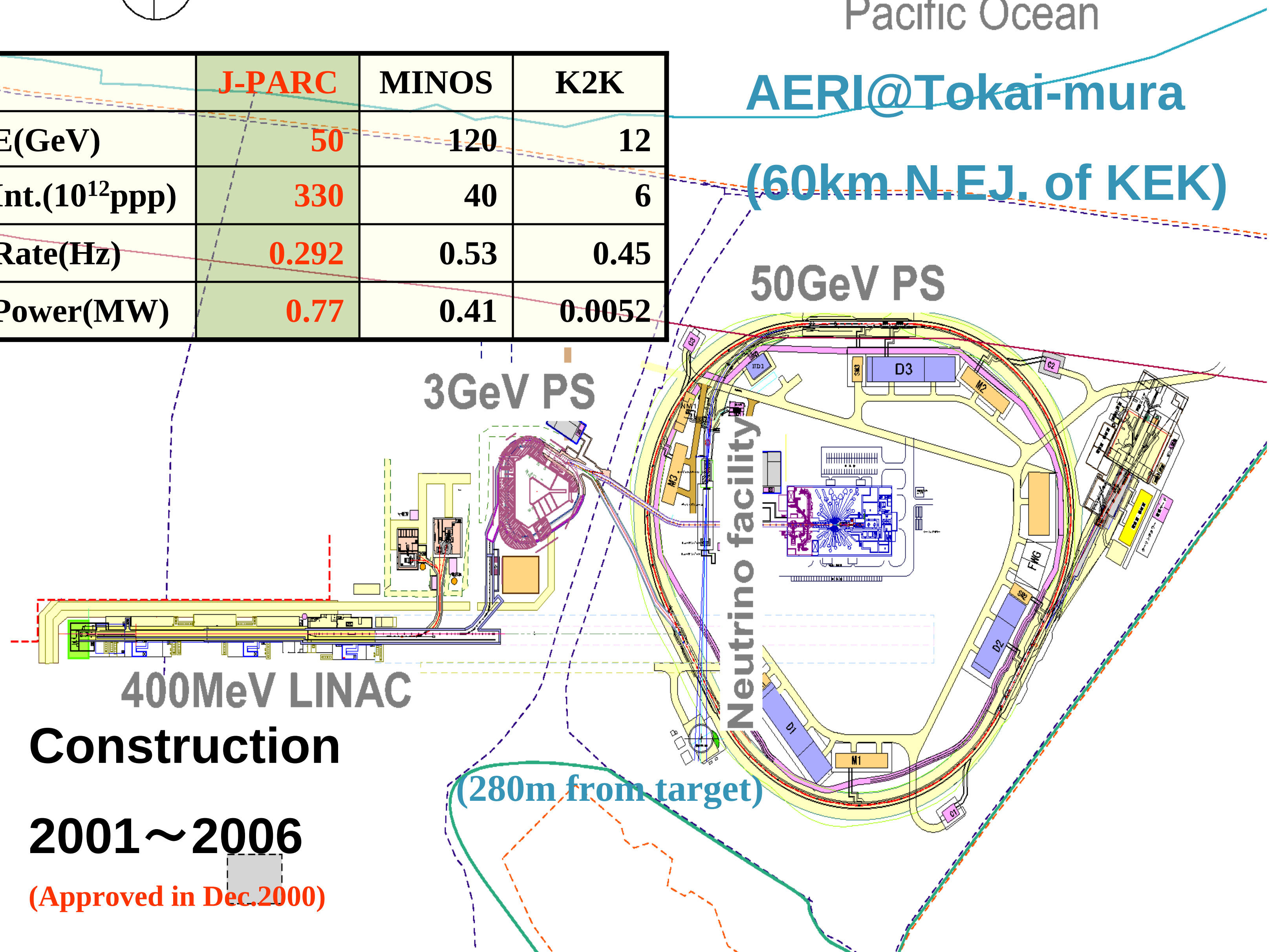
0.73% (**0.15%**@peak) | 1.0% (**0.21%**@peak)

Very small ν_e/ν_μ ratio at ν_μ spectrum peak: **$1\sim2\times10^{-3}$**

JHFnu



	J-PARC	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

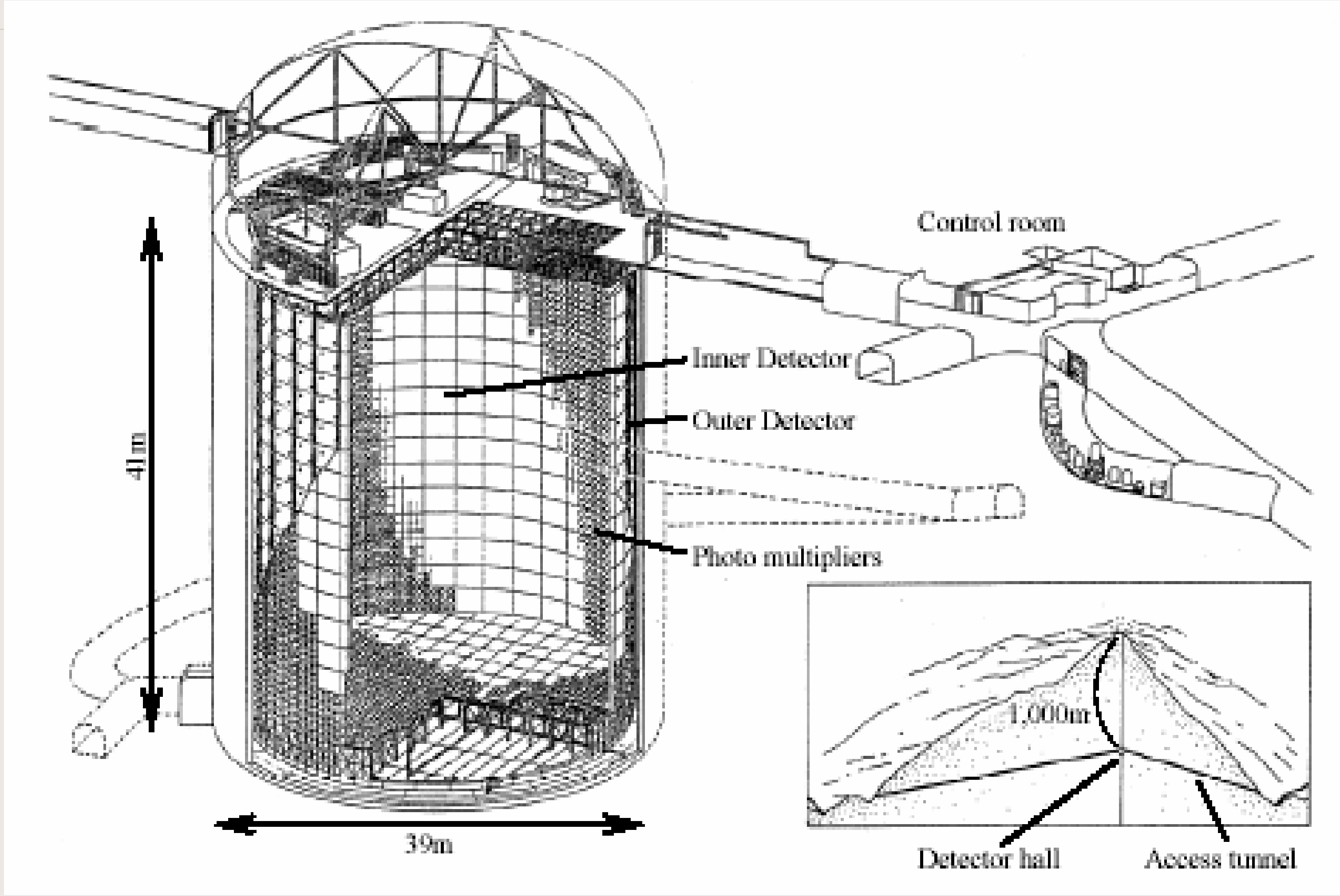


Construction

2001～2006

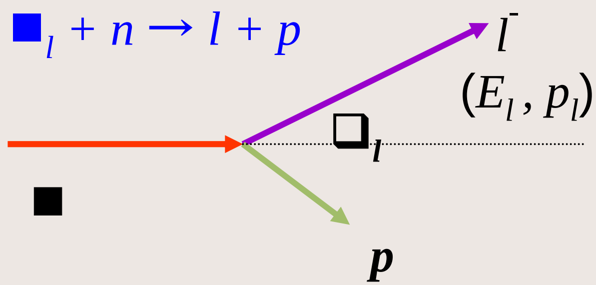
(Approved in Dec.2000)

Far detector: Super-Kamiokande

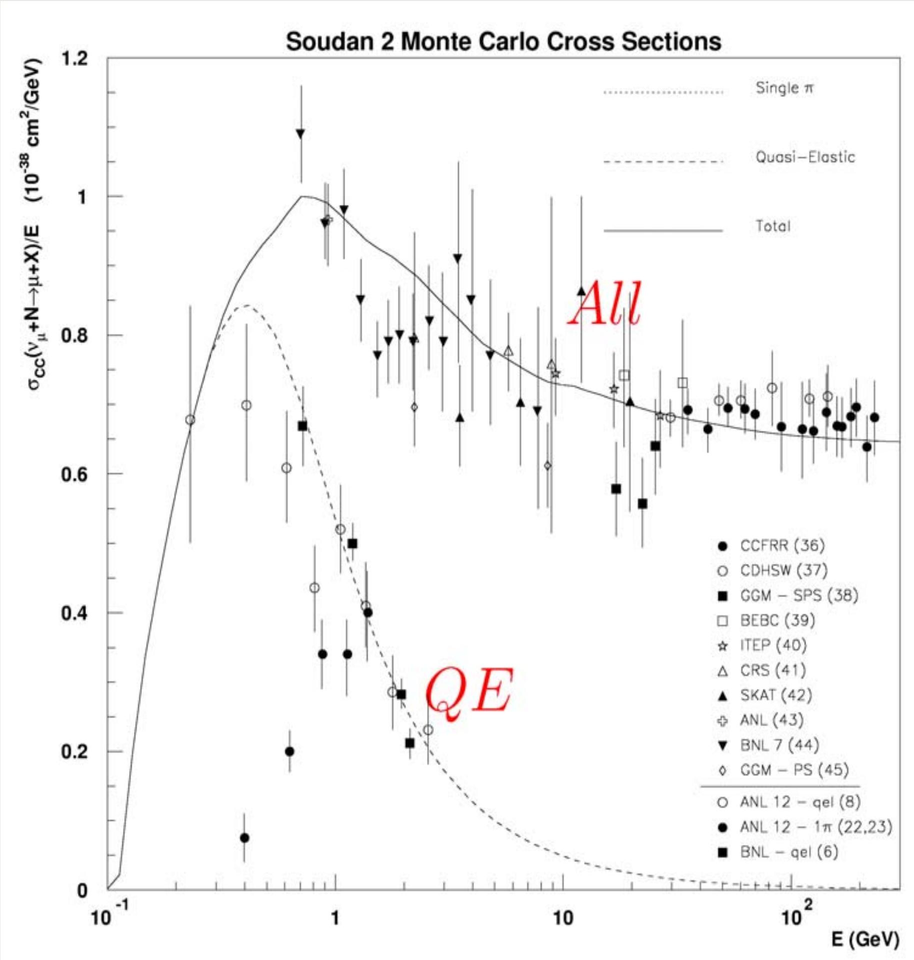


Neutrino Energy Reconstruction

Assume CC quasi elastic (CCQE) reaction



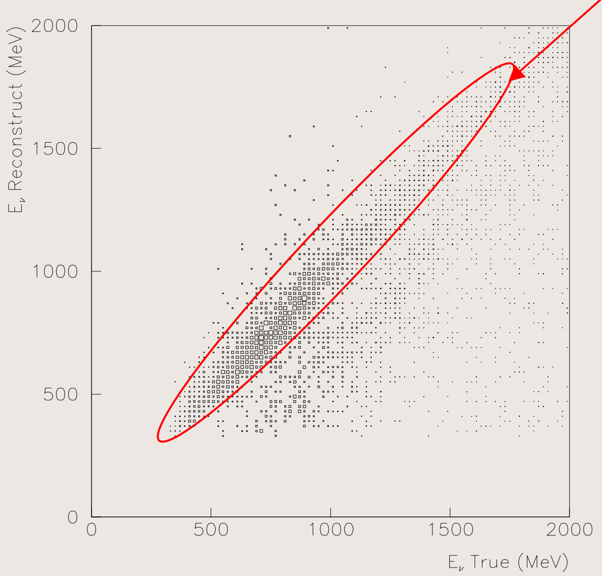
$$E_\nu = \frac{m_N E_l - m_l^2 / 2}{m_N - E_l + p_l \cos\theta_l}$$

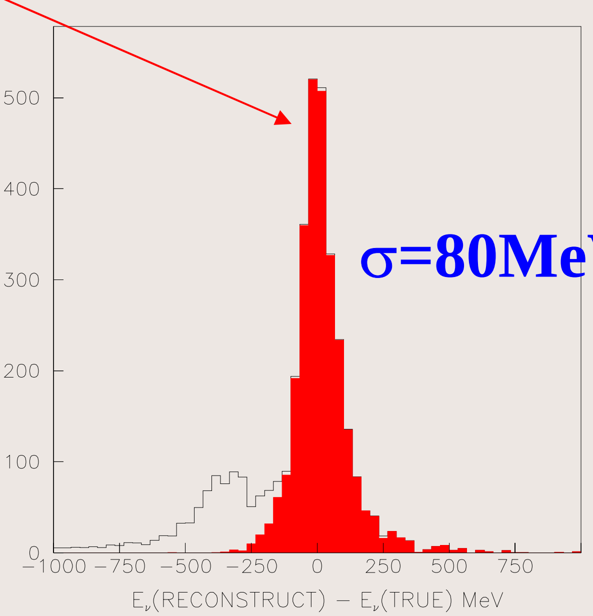


Neutrino Energy Reconstruction

Quasi-elastic

Eν(reconstruct)





σ=80MeV

Eν (True)

Eν(reconstruct) – Eν (True) (MeV)

QE dominate at ～1GeV

NuMI Beam: on and off-axis

- Closer site, in Minnesota
  - About 711 km from Fermilab
  - Close to Soudan Laboratory
  - Unused former mine
  - Utilities available
  - Flexible regarding exact location
- Further site, in Canada
  - About 985 km from Fermilab

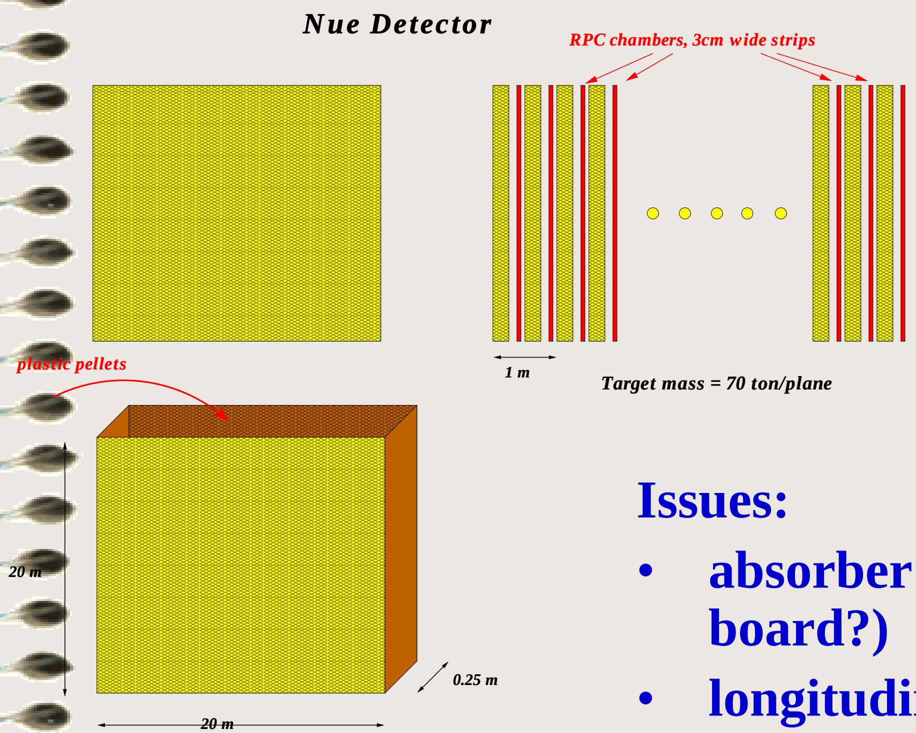
- Selection of sites, baselines, beam energies
- Physics/results driven experiment optimization

NuMI Off-axis Detector

- The goal is an eventual 50 kt fiducial volume detector
- Liquid scintillator strips readout by APDs with particle board absorber is the baseline design
- Backup design is glass RPCs
- Present cost is about 150 M$

An example of a possible detector

Low Z tracking calorimeter



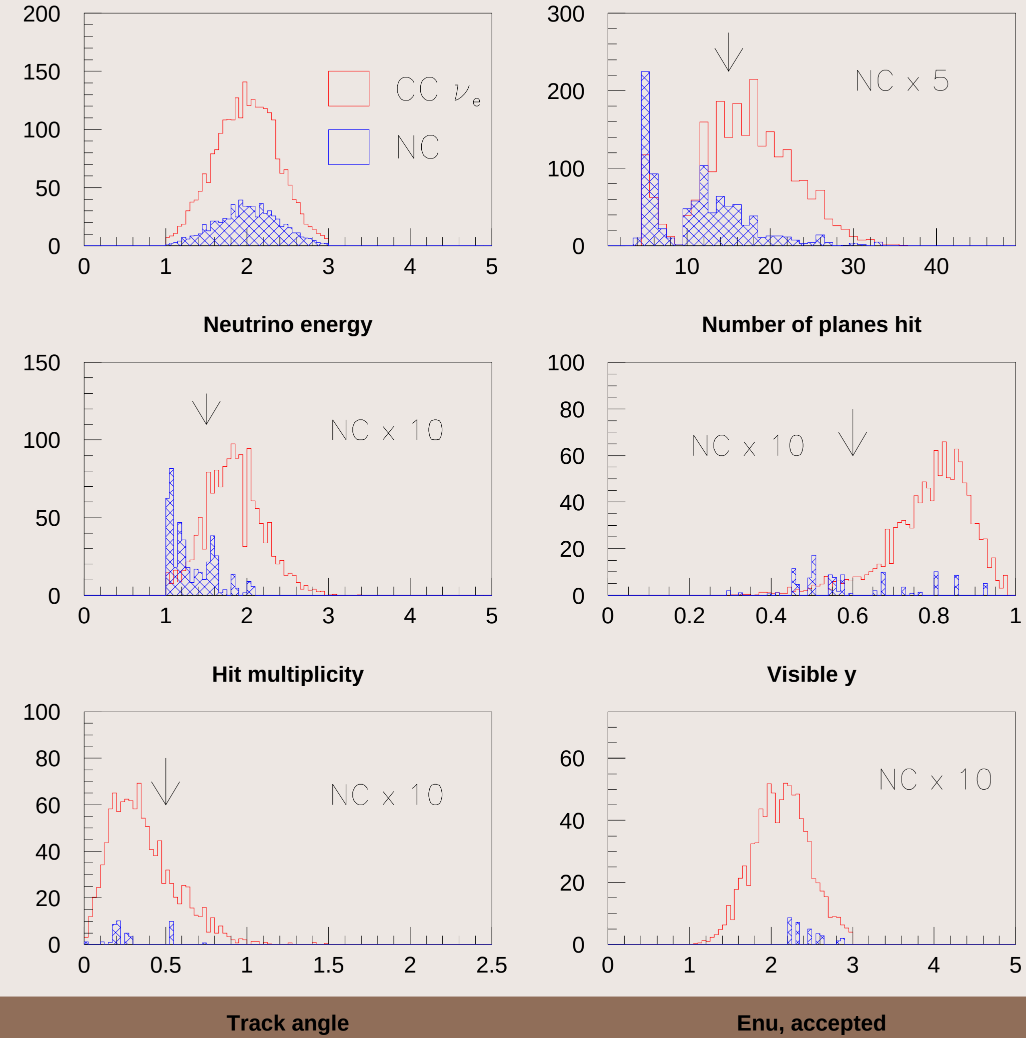
NuMI off-axis detector workshop: January 2003

Issues:

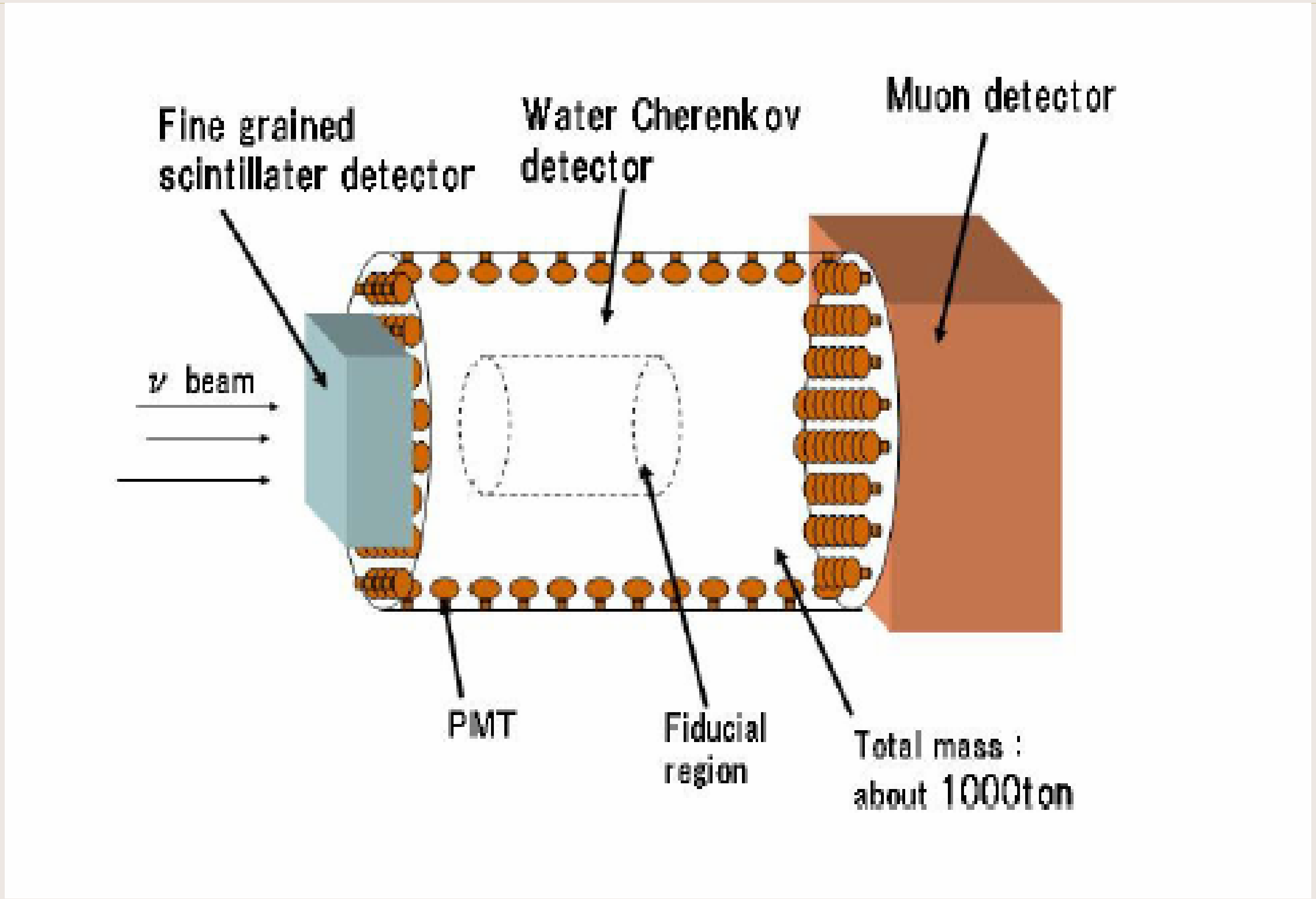
- **absorber material (plastic? Water? Particle board?)**
- **longitudinal sampling (DX_0)?**
- **What is the detector technology (RPC? Scintillator? Drift tubes?)**
- **Transverse segmentation (e/p^0)**
- **Surface detector: cosmic ray background? time resolution?**

CC ν_e vs NC events in a tracking calorimeter: analysis example

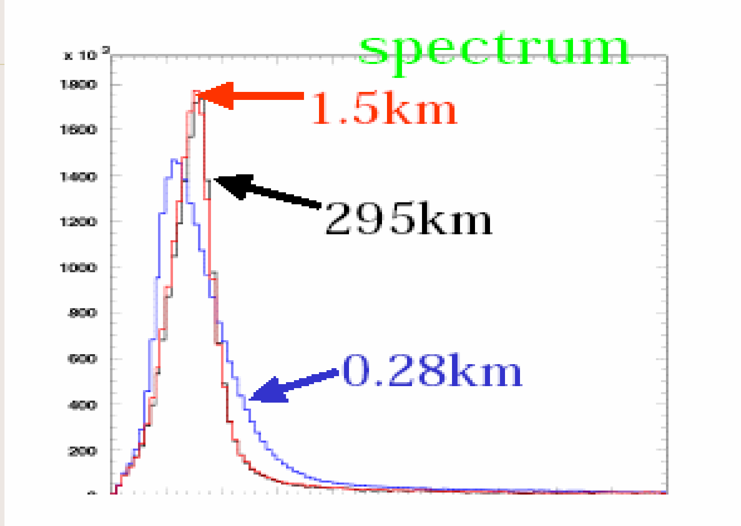
- Electron candidate:
  - Long track
  - 'showering' I.e. multiple hits in a road around the track
  - Large fraction of the event energy
  - 'Small' angle w.r.t. beam
- NC background sample reduced to 0.3% of the final electron neutrino sample (for 100% oscillation probability)
- 35% efficiency for detection/identification of electron neutrinos

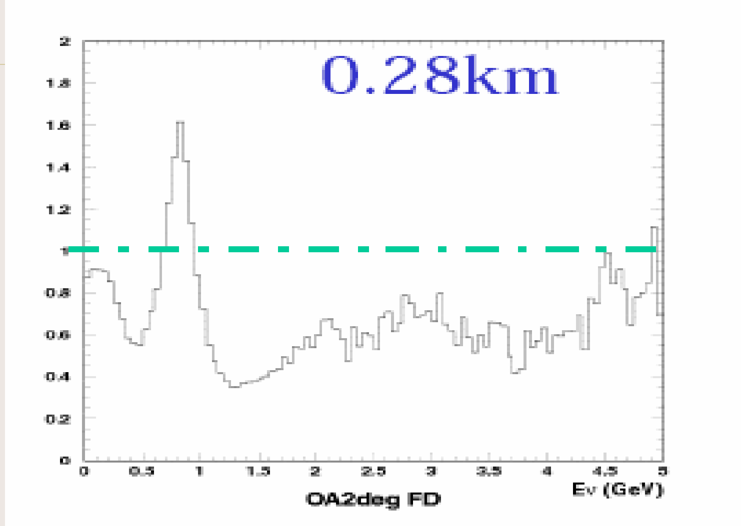


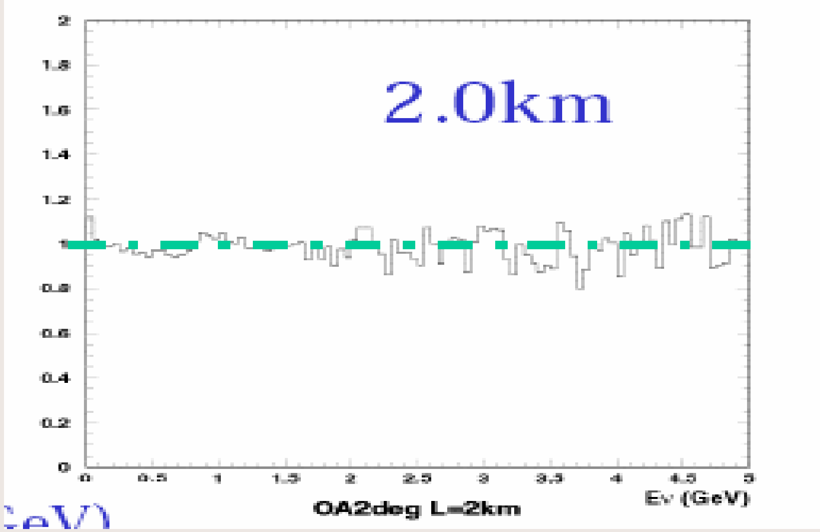
(Near)/Intermediate Detector



Far/Near ratio (OA 2 deg)







Measurements of the neutrino beam:

1) Flux/spectrum for ν_μ and ν_e
2) Profile
3) Stability
4) Event types(QE, single μ ,NC pi0 etc…)
5) Direction

Physics Goal of JHFnu(Phase I)

L=295km, En=0.5~2GeV(Match the WCD)

Precise determination of neutrino oscillation parameters:

$\sin^2 2\theta_{23} \rightarrow 1\%$

$\Delta m_{23}{}^2 \rightarrow 1\times10^{-4}eV^2$

at ($\sin^2 2\theta$=1.0, $\Delta m^2 = 3.2\times10^{-3}eV^2$)

$\sin^2 2\theta_{13} \rightarrow < 1\%$

Physics Goal of JHFnu(Phase II)

CP violation measurement

Proton decay

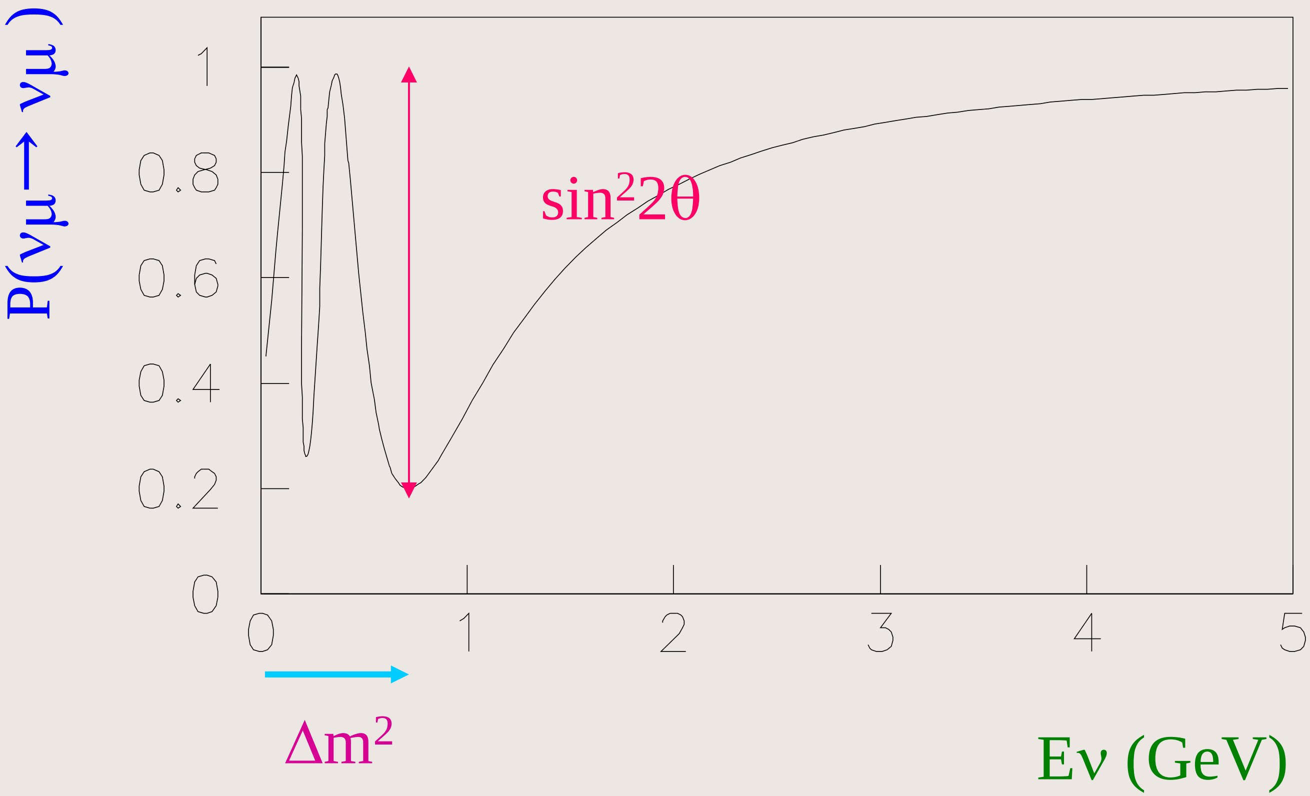
The Physics Goal of NuMI

- Observation of the transition $\nu_\mu \rightarrow \nu_e$
- Measurement of θ_{13}
- Determination of mass hierarchy (sign of Δm_{23})
- Search for CP violation in neutrino sector
- Measurement of CP violation parameters
- Testing CPT with high precision

Δm_{23}^2 and θ_{23} measurement

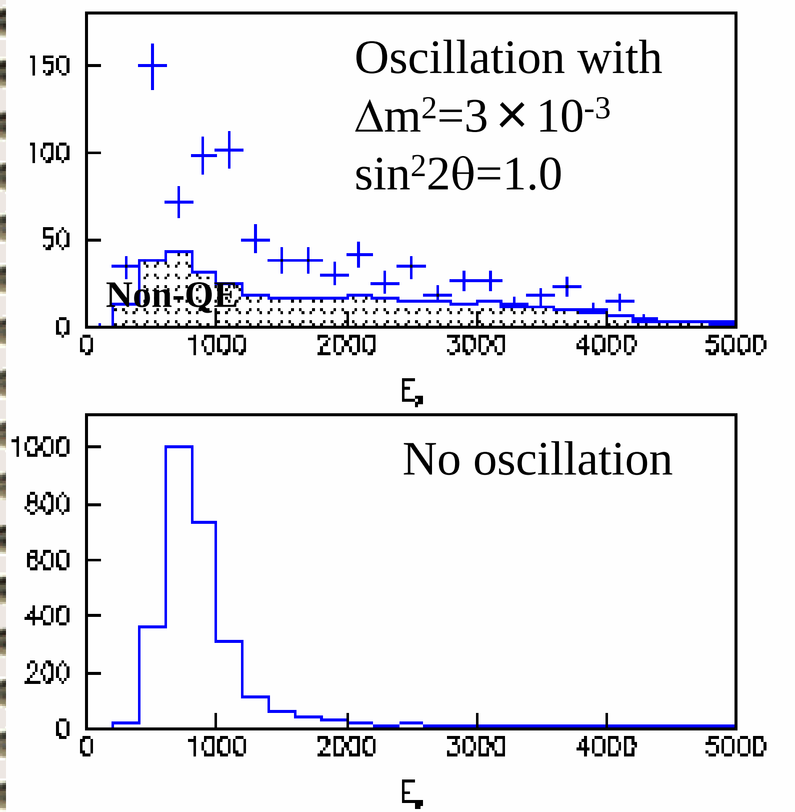
$P(\nu_\mu \rightarrow \nu_\mu) = 1 - \cos^4\theta_{13} \sin^2 2\theta_{23} \sin^2(1.27\ \Delta m_{23}^2\ L/E)$

~1



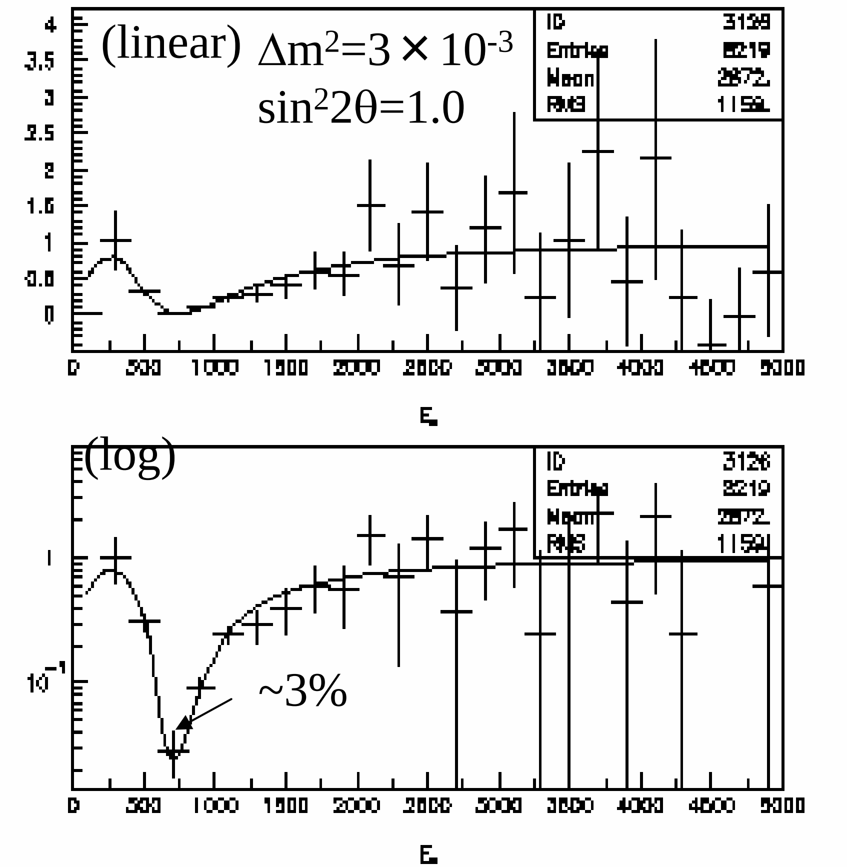
ν_μ disappearance

1ring FC μ-like



Reconstructed Eν (MeV)

Ratio after BG subtraction



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

θ_{13} measurement

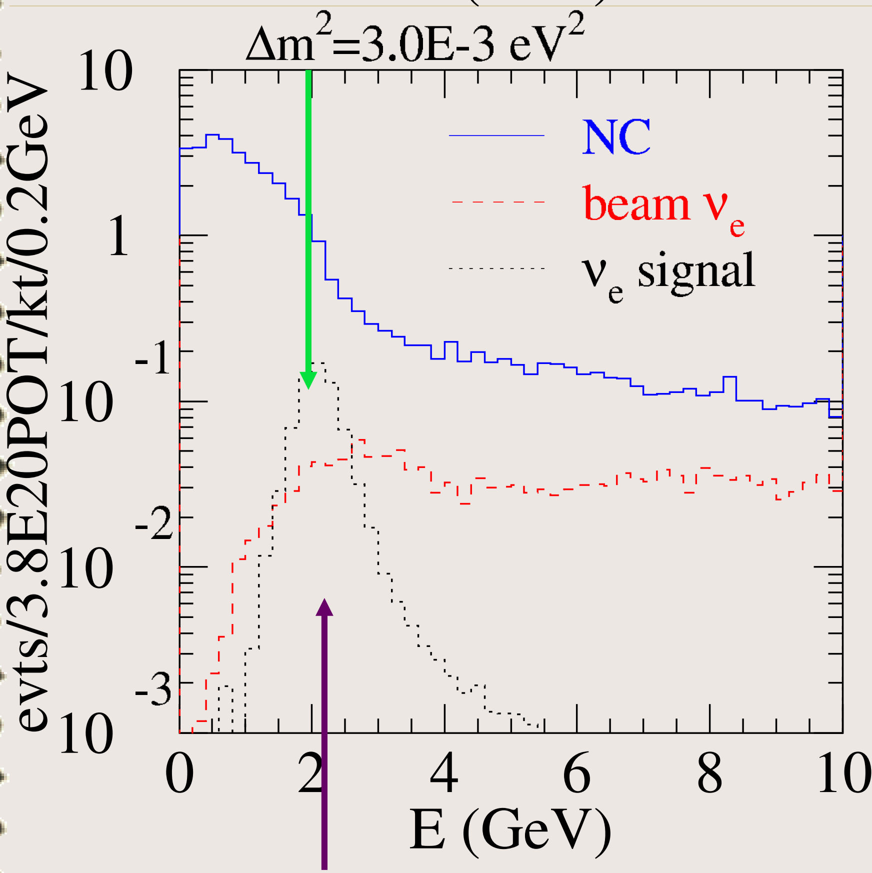
$$P(\nu_\mu \rightarrow \nu_e) = \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2(1.27\, \Delta m_{23}^2\, L/E)$$

- **A mixing angle between 1st and 3rd generation ,** θ_{13} **may be not very small**
- **A discovery of** $\nu_\mu \rightarrow \nu_e$ **can open the new window to study CP violation in this mode**
- **May be a source of baryogenesis in the universe**

θ_{13} Issue

- Oscillation Probability (or $\sin^2 2\theta_{\mu e}$) is not unambigously related to fundamental parameters, θ_{13} or U_{e3}^2
- At low values of $\sin^2 2\theta_{13}$ (~0.01), the uncertainty could be as much as a factor of 4 due to matter and CP effects

Sensitivity dependence on ν_e efficiency and NC rejection



ν_e ($|Ue3|^2$ = 0.01)

- Major improvement of sensitivity by improving ID efficiency up to ~50%
- Factor of ~ 100 rejection power against NC sufficient
- NC background not a major source of the error, but a near detector probably desirable to measure it

Sensitivity to 'nominal' $|U_{e3}|^2$ at the level 0.001 (phase I) and 0.0001 (phase II)

Antineutrinos help greatly

Antineutrinos are crucial to understanding:

- Mass hierarchy
- CP violation
- CPT violation

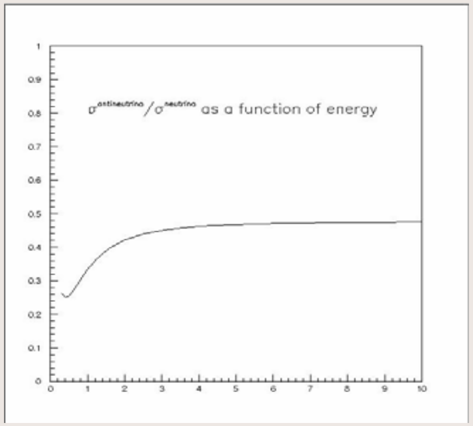
High energy experience: antineutrinos are 'expensive'.

For the same number of POT ← Ingredients: $\sigma(\pi^+)$~$3\sigma(\pi^-)$ (large x)

NuMI ME beam energies:

$\sigma(\pi^+)$~$1.15\sigma(\pi^-)$ (charge conservation!)

Neutrino/antineutrino events/proton ~ 3



(no Pauli exclusion)

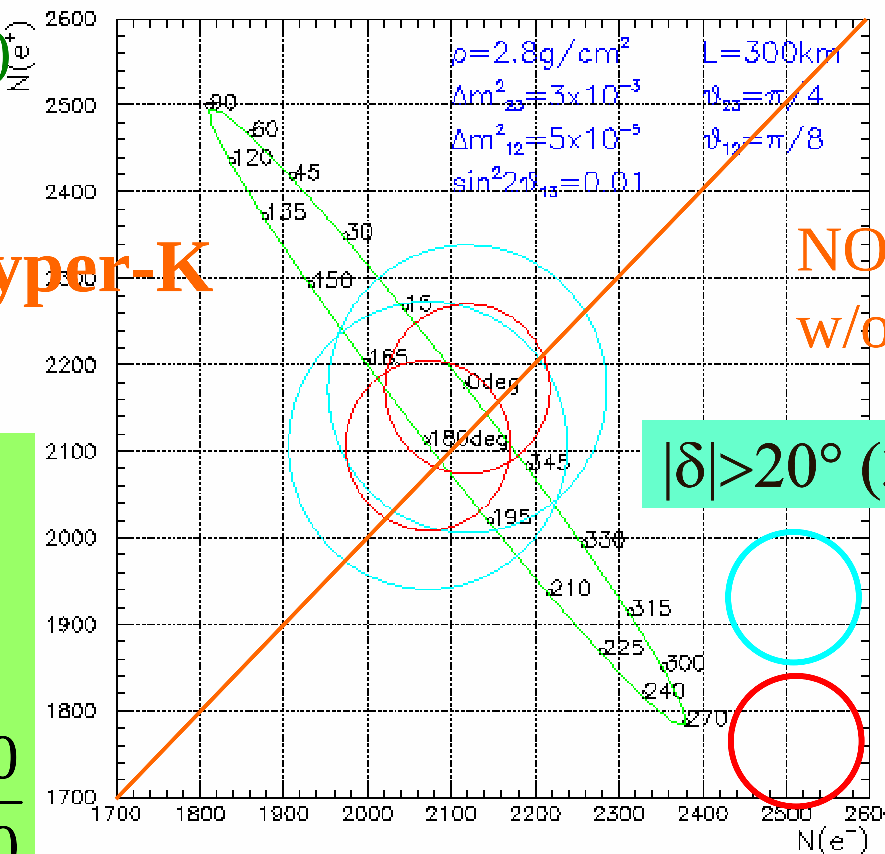
CP Violation Study

- Compare $\nu_\mu \rightarrow \nu_e$ with $\overline{\nu_\mu} \rightarrow \overline{\nu_e}$

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

Phase-II: Hyper-K
1,000 kt

N(e^+)



N(e^-)

NO CP violation
w/o matter effect.

|δ|>20° (3σ **discovery**)

3σ discovery

90% C.L.

Asymmetry

$$\equiv \frac{N(e^+) - N(e^-)}{N(e^+) + N(e^-)}$$

$$\approx \frac{\sim 2000 - \sim 2000}{\sim 2000 + \sim 2000}$$

$$\approx 0.02$$

Letter of Intent (NuMI)

- A Letter of Intent has been submitted to Fermilab in June expressing interest in a new ν effort using off-axis detector in the NuMI beam
- This would most likely be a ~15 year long, 2 phase effort, culminating in study of CP violation
- The LOI was considered by the Fermilab PAC at its Aspen July, 2002, meeting

Schedule of NuMI

- Workshop on detector technology issues planned for January, 2003 (done)
- Proposal to DOE/NSF in early 2003 for support of R&D (done) and subsequent construction of a Near Detector in NuMI beam to be taking data by early 2005
- Proposal for construction of a 25 kt detector in late 2004
- Site selection, experiment approval, and start of construction in late 2005
- Start of data taking in the Far Detector in late 2007
- Formation of an international collaboration to construct a 50 kton detector

Schedule of JHFnu(4 year plan)

- → **KEK(~163 M$)**
- → **MEXT(Ministry of Education,Science and Technology)**
- → **Council for Science and Technology Policy**
- → **Ministry of Finance**

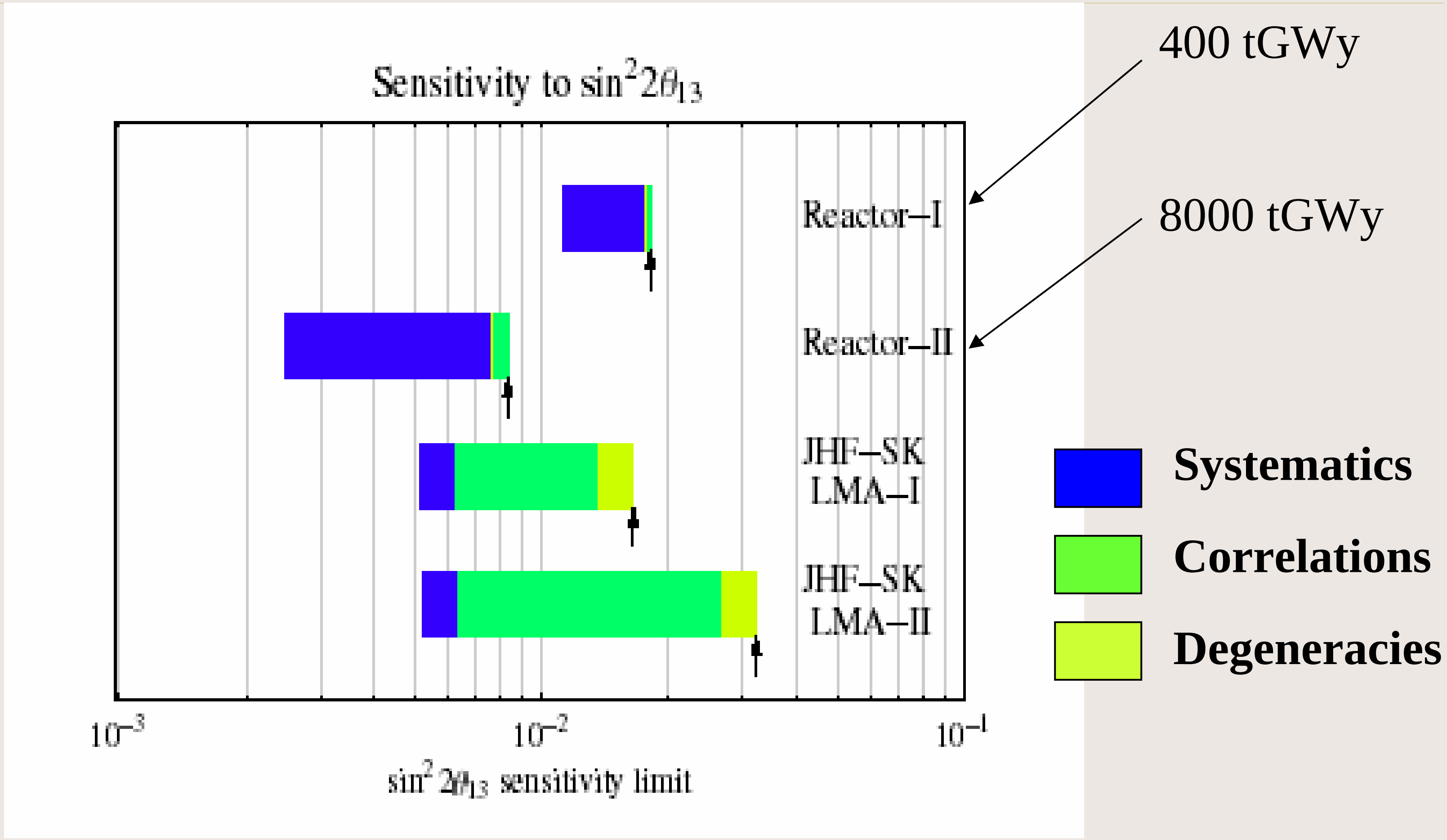
- **Approval for JFY 2005?**

Important Reminder

- The measurement of θ_{13} is made complicated by the fact that oscillation probability is affected by matter effects and possible CP violation
- No unique mathematical relationship between oscillation probability and θ_{13}
- For low values of θ_{13}, sensitivity of an experiment to seeing $\nu_\mu \rightarrow \nu_e$ depends very much on δ
- Several experiments with different conditions and with both ν and $\bar{\nu}$ will be necessary to disentangle these effects
- θ_{13} needs to be sufficiently large if one is to have a chance to investigate CP violation in ν sector

θ_{13} measurement:superbeams vs. reactor

P. Huber et al., hep-ph/0303232



Concluding Remarks

- Neutrino Physics appears to be an exciting field for many years to come
- Most likely several experiments with different running conditions will be required
- Accelerator-based oscillation experiment offer a promising avenue to pursue many physics
- Need direct reactor experiment that measure $\sin^2 2\theta_{13}$ down to the 0.01 level