K2K Results and T2K Project

Kenzo NAKAMURA
KEK

August 1-2, 2005
Neutrino Meeting
IIT-Bombay, Mumbai, India

E. Aliu,[1] S. Andringa,[1] S. Aoki,[10] J. Argyriades,[3] K. Asakura,[10] R. Ashie,[30] H. Berns,[33] H. Bhang,[20] A. Blondel,[26]
S. Borghi,[26] J. Bouchez,[3] J. Burguet-Castell,[32] D. Casper,[28] C. Cavata,[3] A. Cervera,[26] K. O. Cho,[4] J. H. Choi,[4] U. Dore,[19]
X. Espinal,[1] M. Fechner,[3] E. Fernandez,[1] Y. Fukuda,[15] J. Gomez-Cadenas,[32] R. Gran,[33] T. Hara,[10] M. Hasegawa,[12]
T. Hasegawa,[22] K. Hayashi,[12] Y. Hayato,[7] R.L. Helmer,[25] J. Hill,[23] K. Hiraide,[12] J. Hosaka,[30] A. K. Ichikawa,[7] M. Iinuma,[8]
A. Ikeda,[17] T. Inagaki,[12] T. Ishida,[7] K. Ishihara,[30] T. Ishii,[7] M. Ishitsuka,[31] Y. Itow,[30] T. Iwashita,[7] H. I. Jang,[4] E. J. Jeon,[20]
I. S. Jeong,[4] K. Joo,[20] G. Jover,[1] C. K. Jung,[23] T. Kajita,[31] J. Kameda,[30] K. Kaneyuki,[31] I. Kato,[12] E. Kearns,[2] D. Kerr,[23]
C. O. Kim,[11] M. Khabibullin,[9] A. Khotjantsev,[9] D. Kielczewska,[34,21] J. Y. Kim,[4] S. Kim,[20] P. Kitching,[25] K. Kobayashi,[23]
T. Kobayashi,[7] A. Konaka,[25] Y. Koshio,[30] W. Kropp,[28] J. Kubota,[12] Yu. Kudenko,[9] Y. Kuno,[18] T. Kutter,[27,13] J. Learned,[29]
S. Likhoded,[2] I. T. Lim,[4] P. F. Loverre,[19] L. Ludovici,[19] H. Maesaka,[12] J. Mallet,[3] C. Mariani,[19] T. Maruyama,[7]
S. Matsuno,[29] V. Matveev,[9] C. Mauger,[21] K. McConnel,[14] C. McGrew,[23] S. Mikheyev,[9] A. Minamino,[30] S. Mine,[28]
O. Mineev,[9] C. Mitsuda,[30] M. Miura,[30] Y. Moriguchi,[10] T. Morita,[12] S. Moriyama,[30] T. Nakadaira,[12] M. Nakahata,[30]
K. Nakamura,[7] I. Nakano,[17] T. Nakaya,[12] S. Nakayama,[31] T. Namba,[30] R. Nambu,[30] S. Nawang,[8] K. Nishikawa,[12]
K. Nitta,[7] F. Nova,[1] P. Novella,[32] Y. Obayashi,[30] A. Okada,[31] K. Okumura,[31] S. M. Oser,[27] Y. Oyama,[7] M. Y. Pac,[5]
F. Pierre,[3] A. Rodriguez,[1] C. Saji,[31] M. Sakuda,[7,17] F. Sanchez,[1] A. Sarrat,[23] T. Sasaki,[12] K. Scholberg,[6,14] R. Schroeter,[26]
M. Sekiguchi,[10] E. Sharkey,[23] M. Shiozawa,[30] K. Shiraishi,[33] G. Sitjes,[32] M. Smy,[28] H. Sobel,[28] J. Stone,[2] L. Sulak,[2]
A. Suzuki,[10] Y. Suzuki,[30] T. Takahashi,[8] Y. Takenaga,[31] Y. Takeuchi,[30] K. Taki,[30] Y. Takubo,[18] N. Tamura,[16] M. Tanaka,[7]
R. Terri,[23] S. T'Jampens,[3] A. Tornero-Lopez,[32] Y. Totsuka,[7] S. Ueda,[12] M. Vagins,[28] C. W. Walter,[6] W. Wang,[2]
R. J. Wilkes,[33] S. Yamada,[9] S. Yamamoto,[12] C. Yanagisawa,[23] N. Yershov,[9] H. Yokoyama,[24] M. Yokoyama,[12] J. Yoo,[20]
M. Yoshida,[18] and J. Zalipska[21]

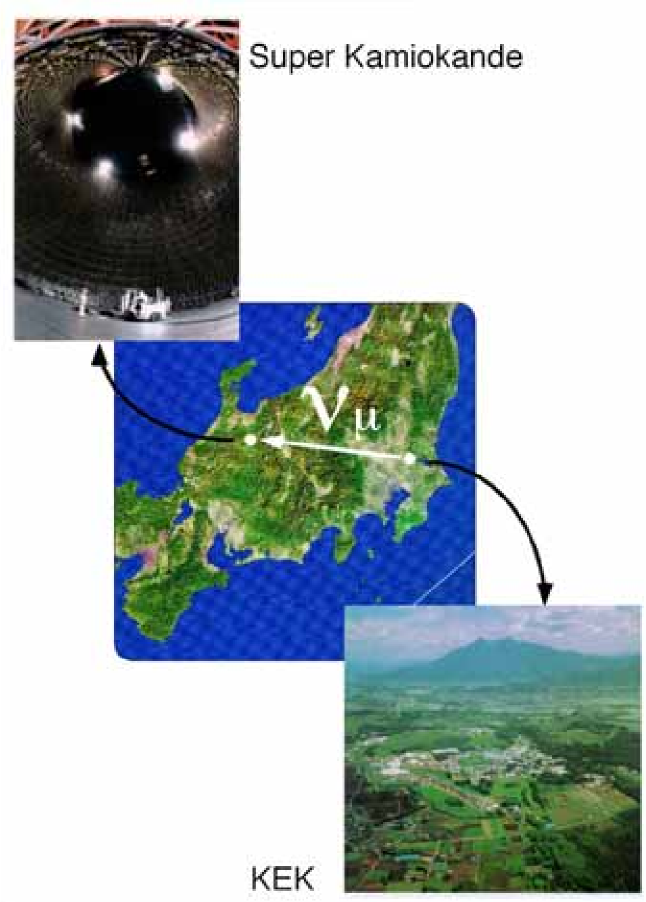
(The K2K Collaboration)

[1] *Institut de Fisica d'Altes Energies, Universitat Autonoma de Barcelona, E-08193 Bellaterra (Barcelona), Spain*
[2] *Department of Physics, Boston University, Boston, Massachusetts 02215, USA*
[3] *DAPNIA, CEA Saclay, 91191 Gif-sur-Yvette Cedex, France*
[4] *Department of Physics, Chonnam National University, Kwangju 500-757, Korea*
[5] *Department of Physics, Dongshin University, Naju 520-714, Korea*
[6] *Department of Physics, Duke University, Durham, North Carolina 27708, USA*
[7] *High Energy Accelerator Research Organization (KEK), Tsukuba, Ibaraki 305-0801, Japan*
[8] *Graduate School of Advanced Sciences of Matter, Hiroshima University, Higashi-Hiroshima, Hiroshima 739-8530, Japan*
[9] *Institute for Nuclear Research, Moscow 117312, Russia*
[10] *Kobe University, Kobe, Hyogo 657-8501, Japan*
[11] *Department of Physics, Korea University, Seoul 136-701, Korea*
[12] *Department of Physics, Kyoto University, Kyoto 606-8502, Japan*
[13] *Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70803-4001, USA*
[14] *Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA*
[15] *Department of Physics, Miyagi University of Education, Sendai 980-0845, Japan*
[16] *Department of Physics, Niigata University, Niigata, Niigata 950-2181, Japan*
[17] *Department of Physics, Okayama University, Okayama, Okayama 700-8530, Japan*
[18] *Department of Physics, Osaka University, Toyonaka, Osaka 560-0043, Japan*
[19] *University of Rome La Sapienza and INFN, I-000185 Rome, Italy*
[20] *Department of Physics, Seoul National University, Seoul 151-747, Korea*
[21] *A. Soltan Institute for Nuclear Studies, 00-681 Warsaw, Poland*
[22] *Research Center for Neutrino Science, Tohoku University, Sendai, Miyagi 980-8578, Japan*
[23] *Department of Physics and Astronomy, State University of New York, Stony Brook, New York 11794-3800, USA*
[24] *Department of Physics, Tokyo University of Science, Noda, Chiba 278-0022, Japan*
[25] *TRIUMF, Vancouver, British Columbia, V6T 2A3, Canada*
[26] *DPNC, Section de Physique, University of Geneva, CH1211, Geneva 4, Switzerland*
[27] *Department of Physics & Astronomy, University of British Columbia, Vancouver, British Columbia, V6T 1Z1, Canada*
[28] *Department of Physics and Astronomy, University of California, Irvine, California 92697-4575, USA*
[29] *Department of Physics and Astronomy, University of Hawaii, Honolulu, Hawaii 96822, USA*
[30] *Kamioka Observatory, Institute for Cosmic Ray Research, University of Tokyo, Kamioka, Gifu 506-1205, Japan*
[31] *Research Center for Cosmic Neutrinos, Institute for Cosmic Ray Research, University of Tokyo, Kashiwa, Chiba 277-8582, Japan*
[32] *Instituto de Fisica Corpuscular, E-46071 Valencia, Spain*
[33] *Department of Physics, University of Washington, Seattle, Washington 98195-1560, USA*
[34] *Institute of Experimental Physics, Warsaw University, 00-681 Warsaw, Poland*

K2K aims at

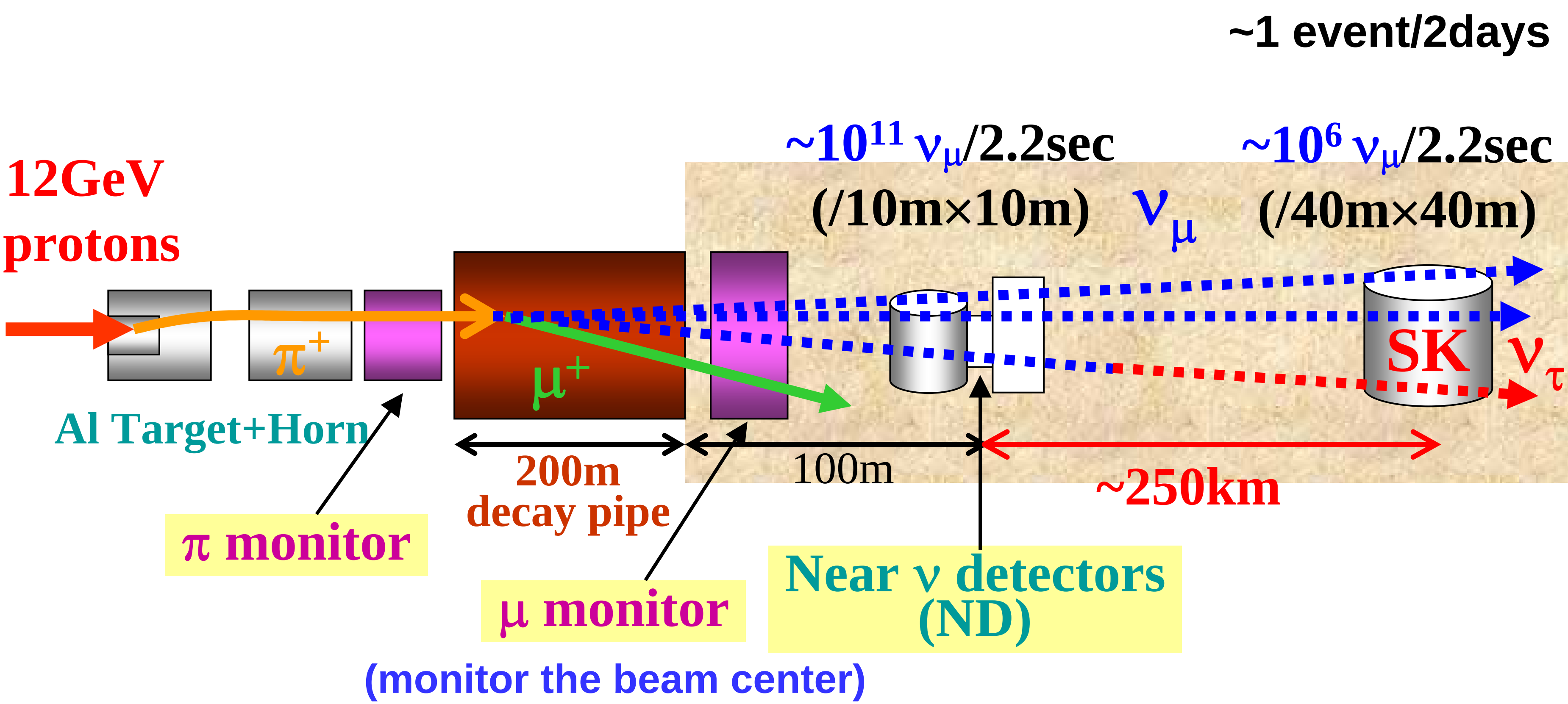
- Confirmation of the Super-Kamiokande's results on atmospheric neutrino oscillation with ν_μ disappearance by
  - Counting the observed number of events in the far detector and comparing it with the expected number of events for no oscillation.
  - Comparing the near and far spectra
    - Observation of oscillation pattern as a function of energy
- Measurements of neutrino interaction cross sections in the GeV region

K2K (KEK-to-Kamioka)



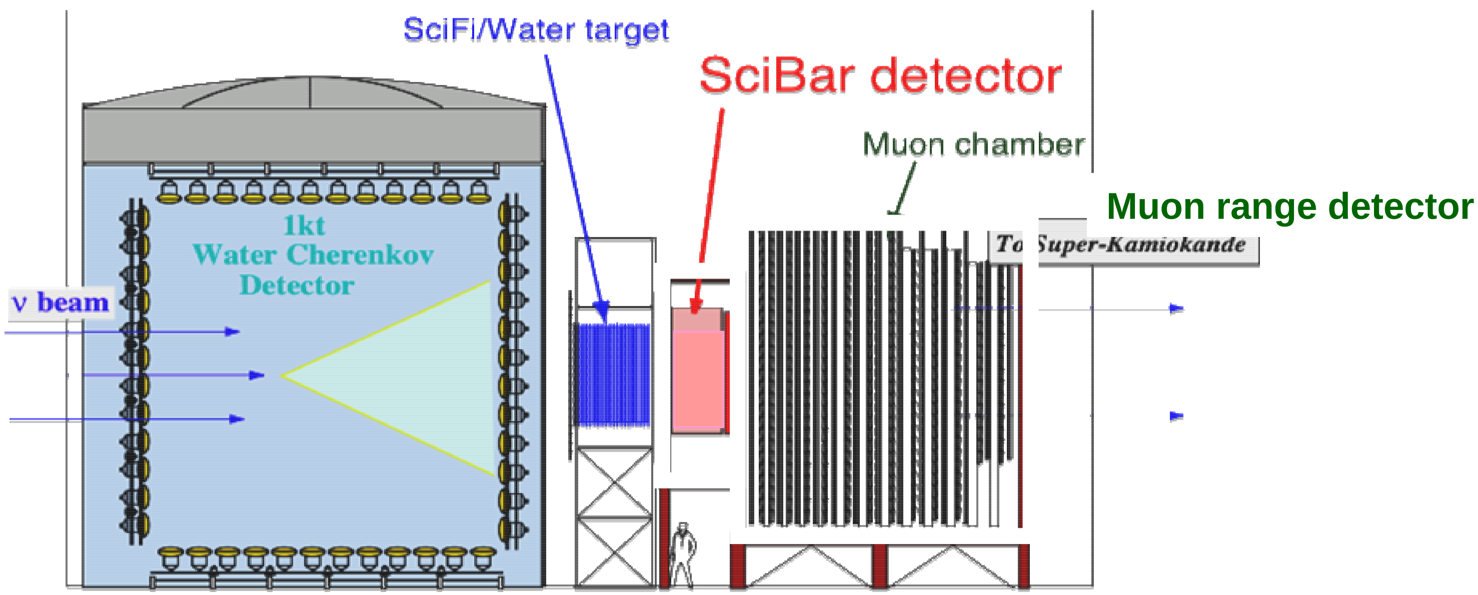
- **Accelerator: 12 GeV proton synchrotron**
  Beam intensity: 6×10^{12} protons / pulse
  Repetition: 1 pulse / 2.2 sec
  Pulse width: 1.1 μs (9 bunches)
- **Horn-focused wide-band beam**
  Average neutrino energy: 1.3 GeV
- **Near detector: 300 m from the target**
- **Far detector (Super-Kamiokande):**
  250 km from the target
- **Goal: 10^{20} POT (protons on target)**
- **K2K-I started: April 1999**
- **K2K-II started: December 2002**
- **K2K-II terminated: November 2004**

Conceptual Layout

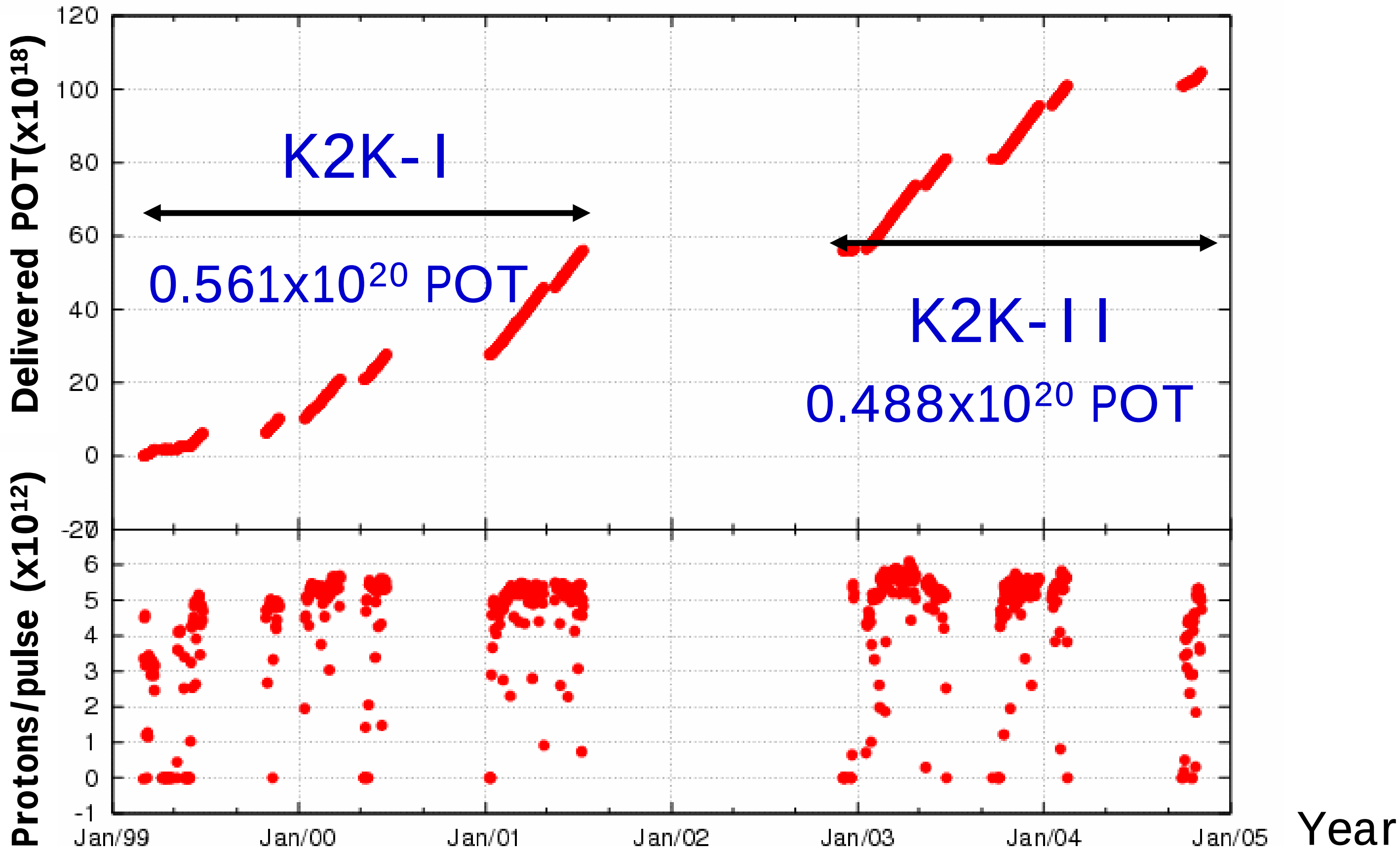


Near Detector Complex

- 1KT Water Cherenkov Detector (1KT)
- Scintillating-fiber/Water Sandwich Detector (SciFi)
- Lead Glass calorimeter (LG) before 2002
- Scintillator Bar Detector (SciBar) after 2003
- Muon Range Detector (MRD)

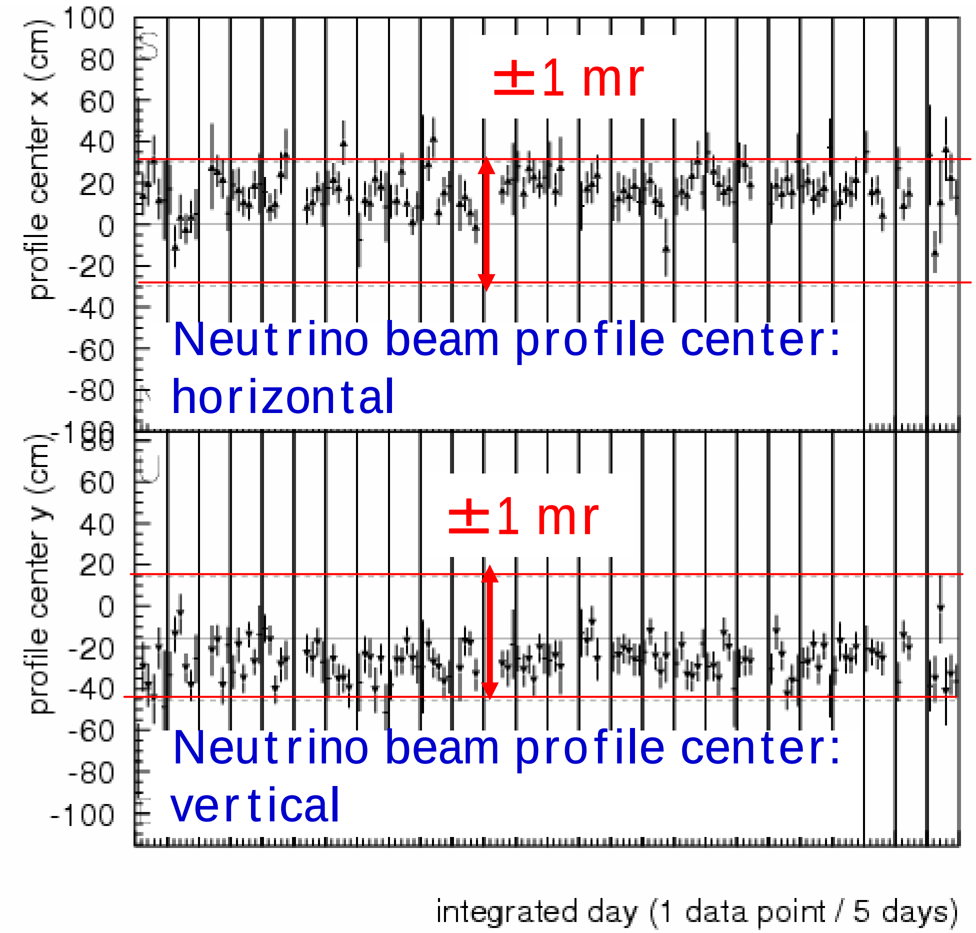


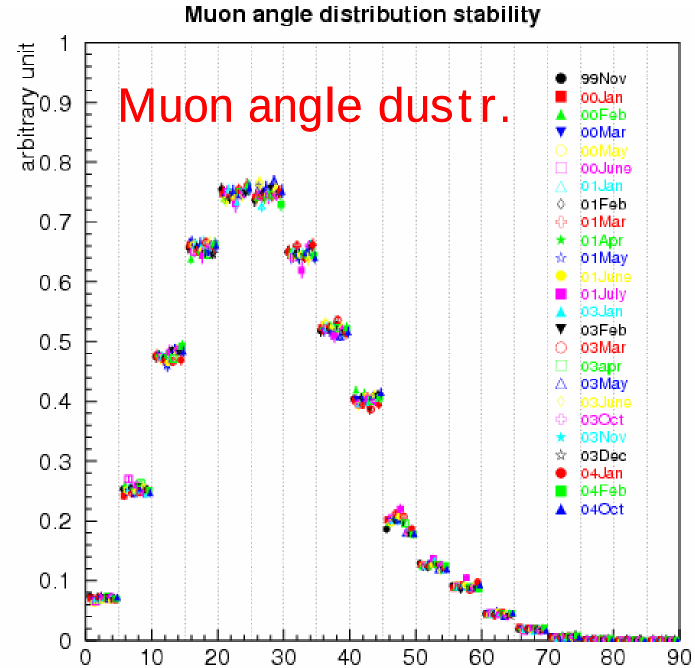
Beam

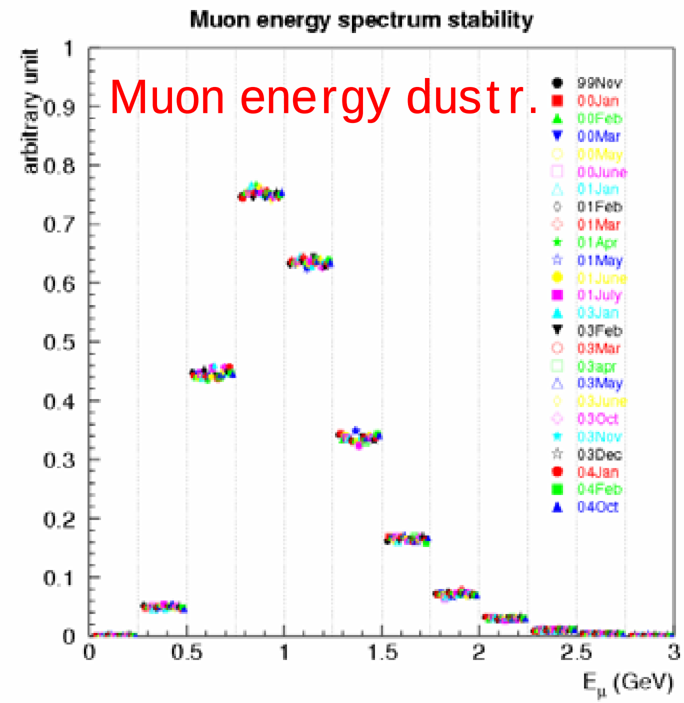


- Total POT delivered: 1.049×10^{20}
- Used for analysis: 0.922×10^{20}

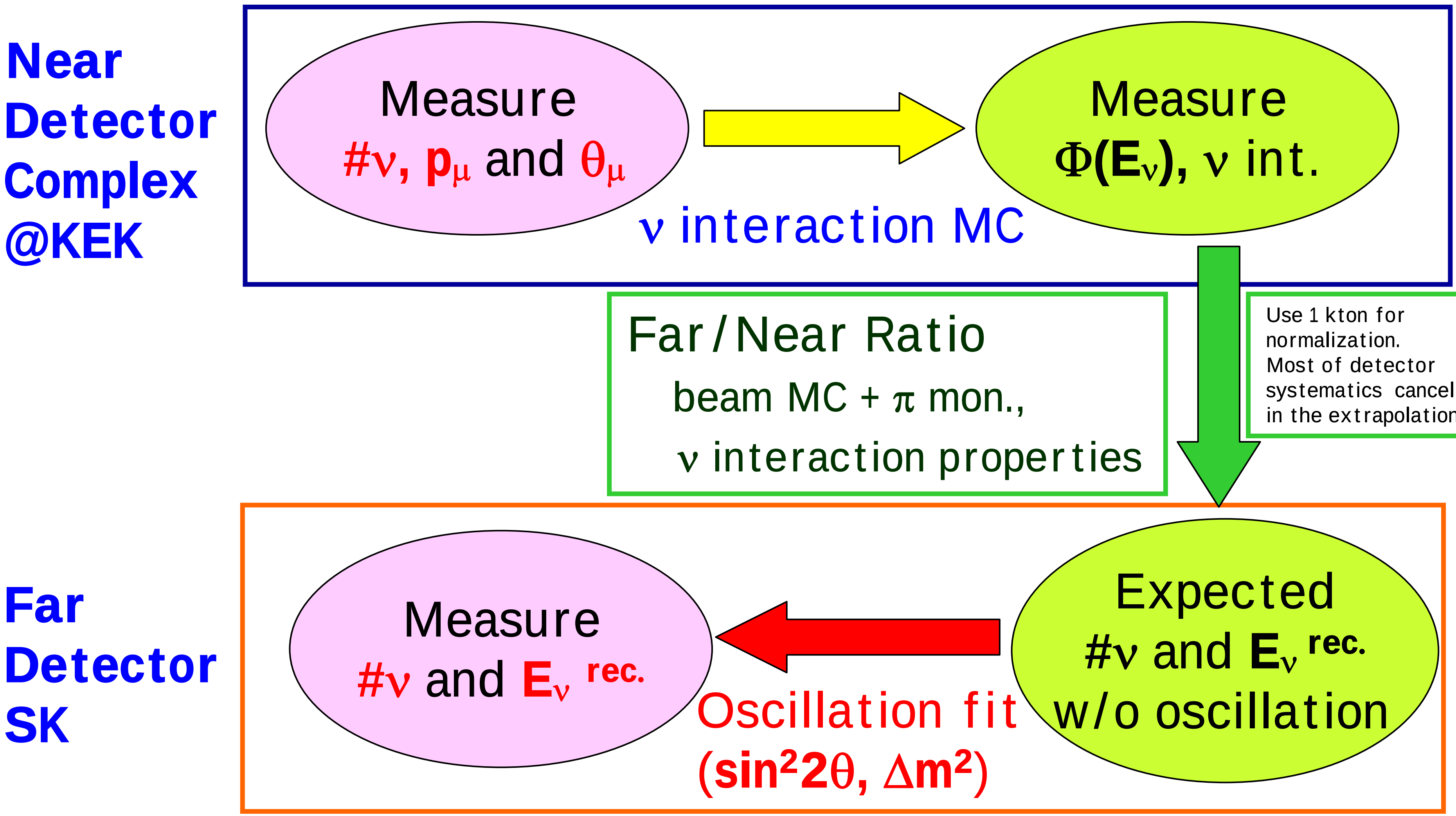
Stability of the beam has been monitored by MRD







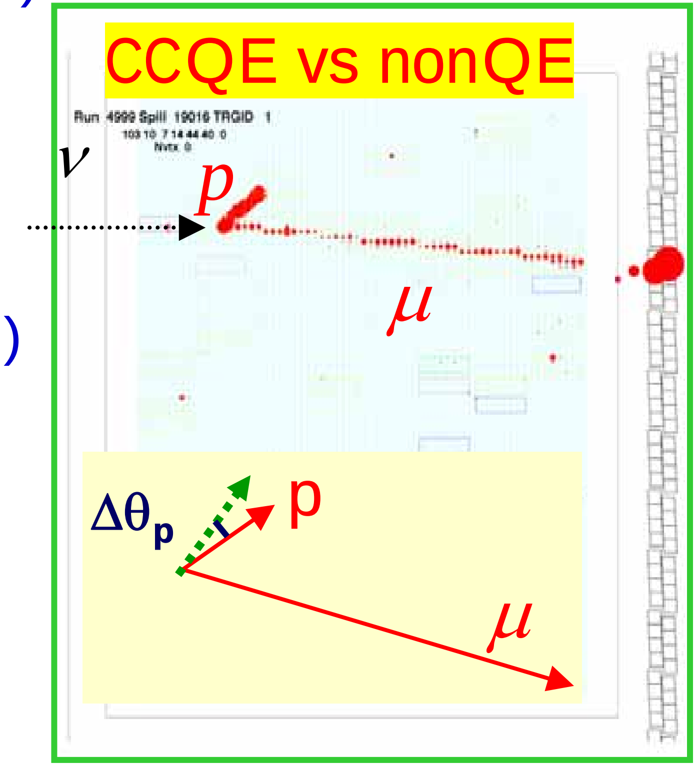
Analysis Strategy



Spectrum Measurement at Near Site

- For the following data samples, simultaneously fit (P_μ, Θ_μ) distributions with Monte Carlo templates (see next slide).

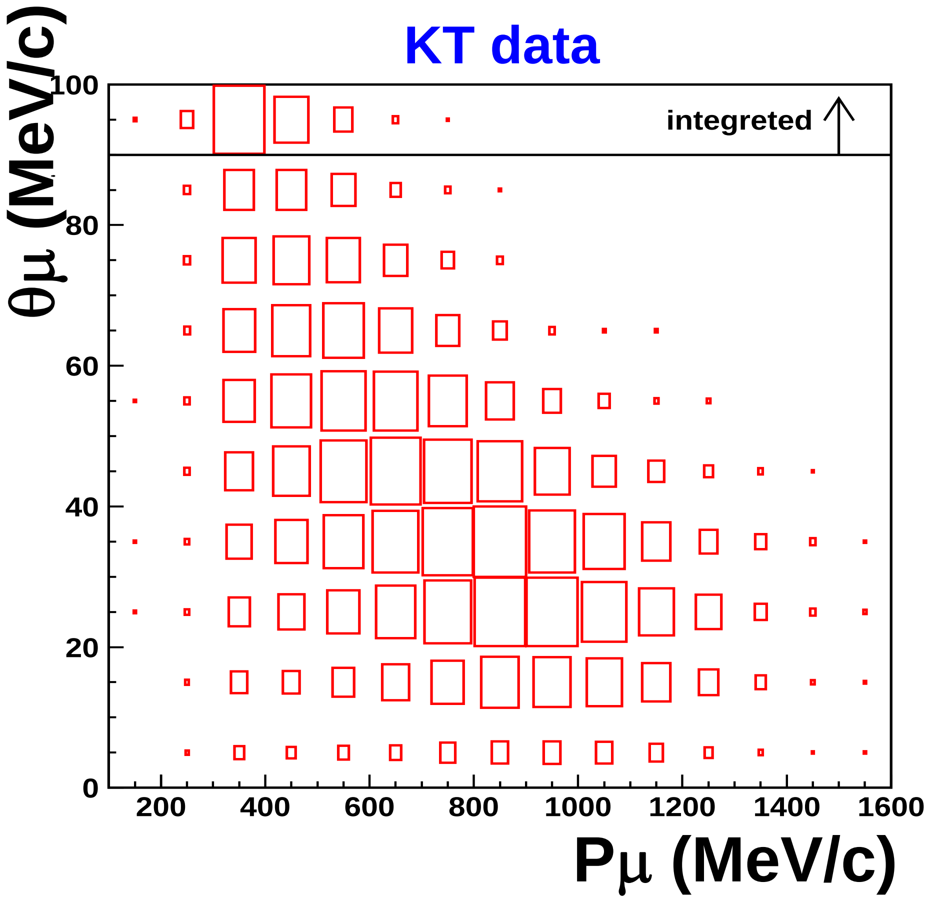
- 1KT Water Cherenkov detector (H,O target)
  - 1. Fully contained one-ring muon-like sample
- SciFi fiber tracker (H,O target)
  - 2. Single-muon track sample
  - 3. Two-track QE sample ($\Delta\theta_p<25^\circ$)
  - 4. Two-tracks nonQE sample ($\Delta\theta_p>30^\circ$)
- SciBar fine-grained scintillator (H,C target)
  - 5. Single-muon track sample
  - 6. Two-track QE sample ($\Delta\theta_p<25^\circ$)
  - 7. Two-tracks nonQE sample ($\Delta\theta_p>25^\circ$)



- Free parameters of the fit
  - flux in 8 energy bins $\Phi(E_\nu)$
  - nonQE/QE
  - detector uncertainties (energy scale, efficiencies,...)
  - nuclear effect uncertainties (proton and pion rescattering)

Example of the data and MC templates

KT data



Eν

QE (MC)

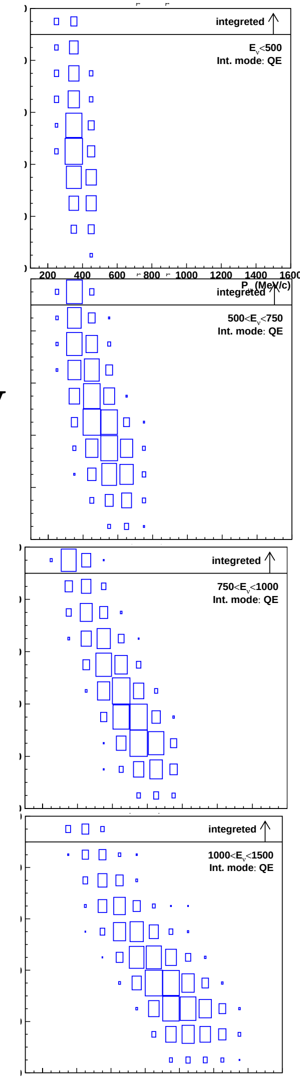
nQE(MC)

0-0.5 GeV

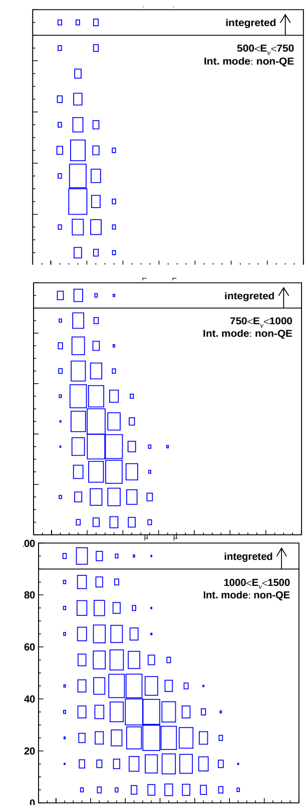
0.5-0.75GeV

0.75-1.0GeV

1.0-1.5GeV

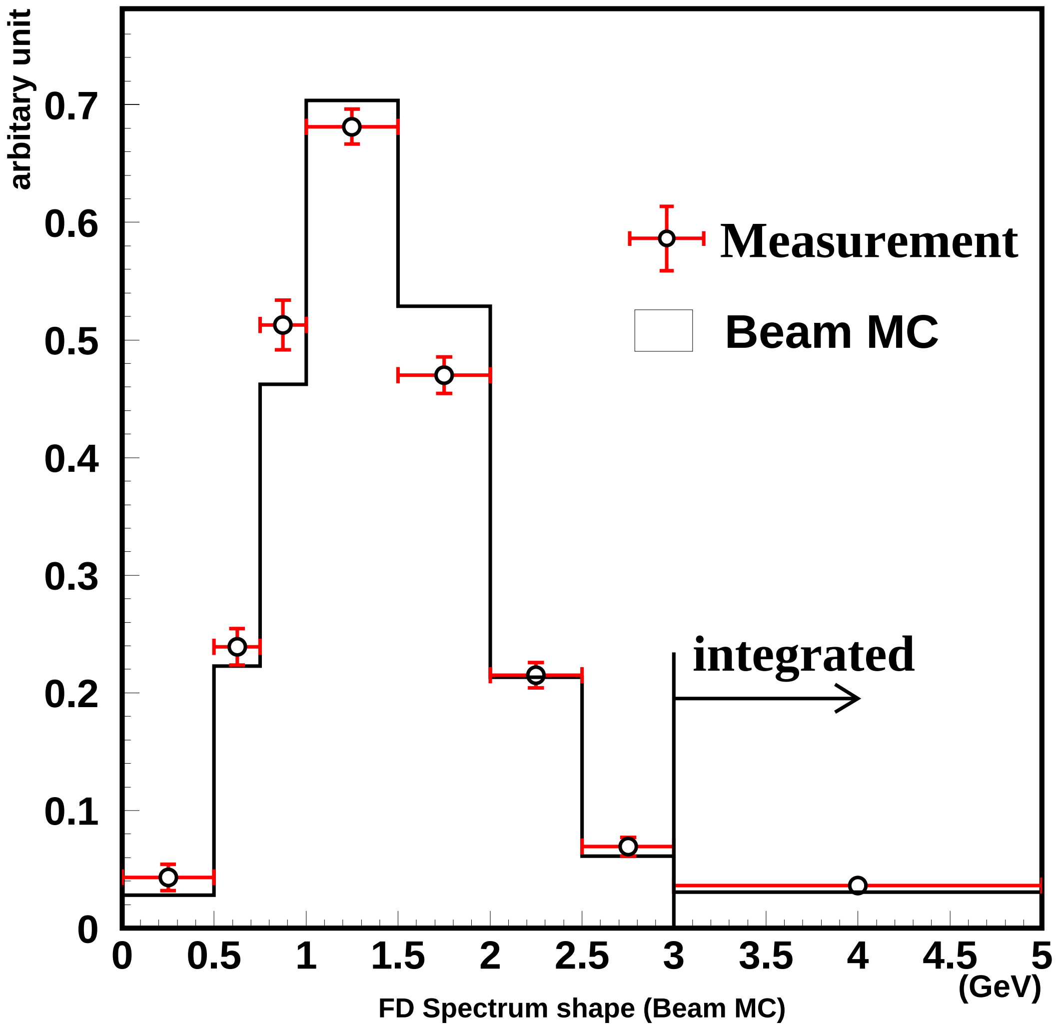


MC templates

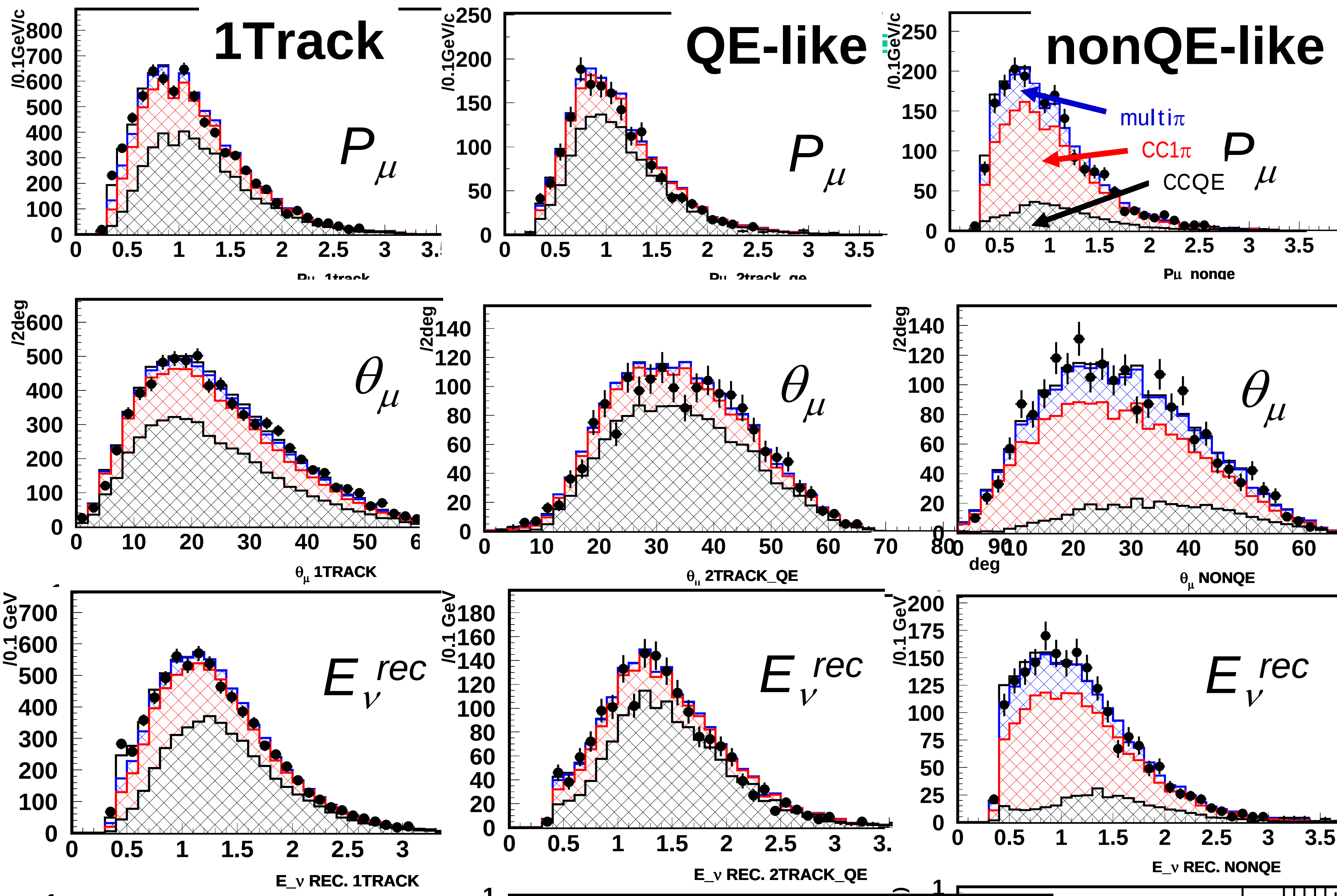


- ν flux $\Phi_{KEK}(E_\nu)$ (8 bins)
- ν interaction (nQE/QE)

Neutrino Energy Spectrum at Near Site

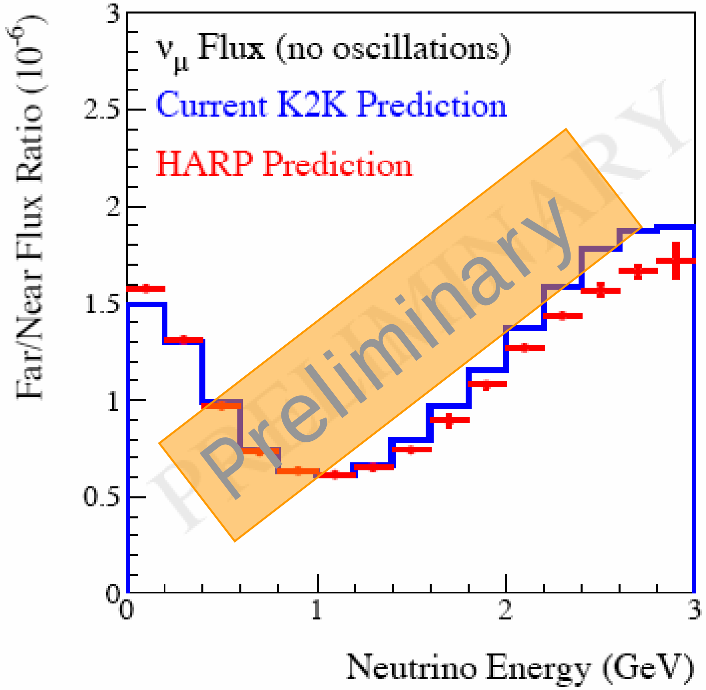


Example of fitted Distributions (SciBar)



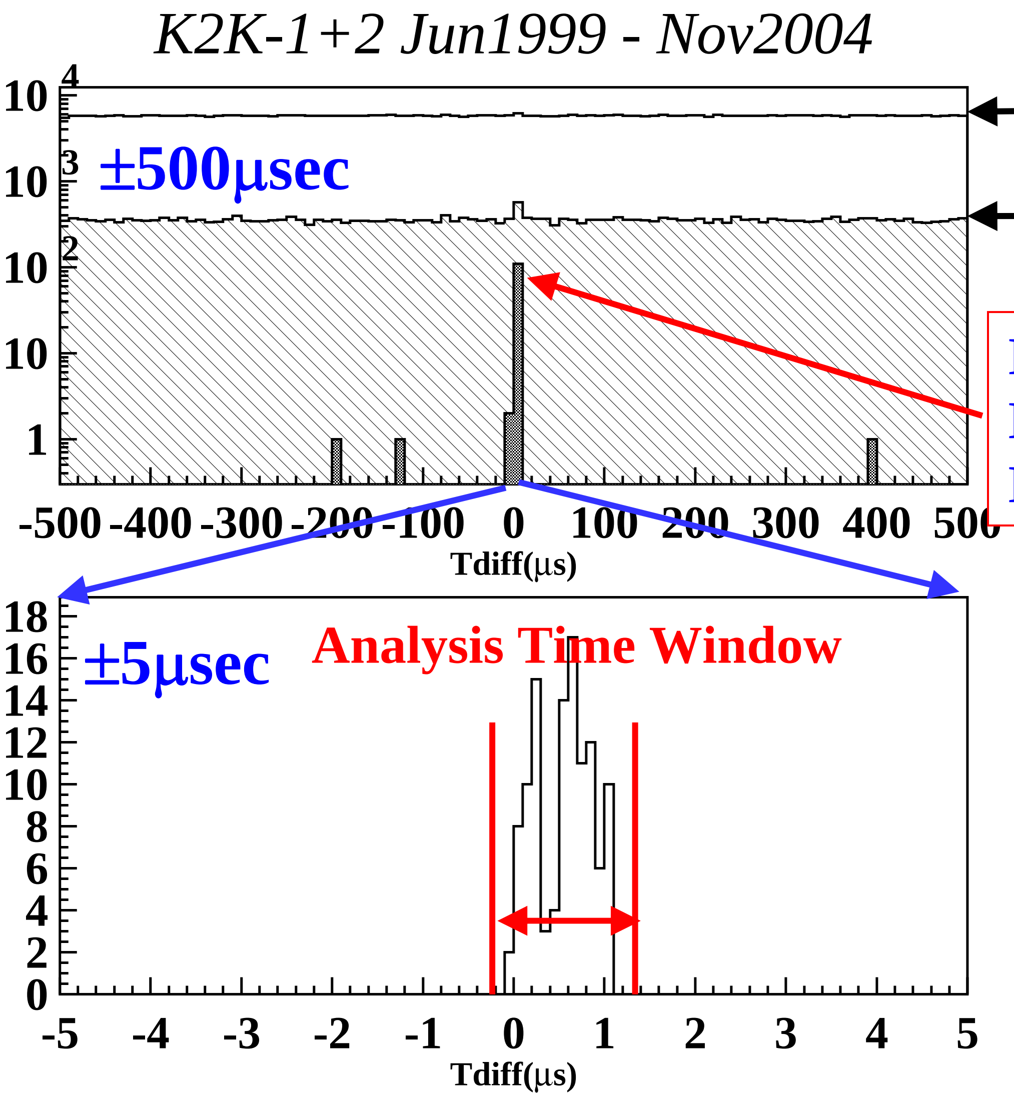
HARP measurements will reduce the systematic error of the F/N ratio (now ~5%)

Expectations for Far/Near Flux Ratio



- F/N flux ratios predicted by the default K2K assumptions, and by HARP, are very similar. Neglecting ν xsec, efficiencies, etc., for $0 < E_\nu < 3$ GeV: $(\mathrm{F/N})_{\mathrm{WANG2}} = 0.8264 \cdot 10^{-6}$, $(\mathrm{F/N})_{\mathrm{HARP}} = 0.8246 \cdot 10^{-6}$ (-0.2%)

SK Events



Decay electron cut.

≥ 30MeV Deposited Energy

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

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

(BG: 1.7 events within ±500μs
2.5×10^{-3} events in 1.5μs)

SK Event Summary

K2K-I+II	N_{sk}^{obs}	N_{sk}^{pred}
FC in 22.5kt	112	155.9
1ring	67	99.0
μ-like	58	90.8
e-like	9	8.2
Multi Ring	45	56.8

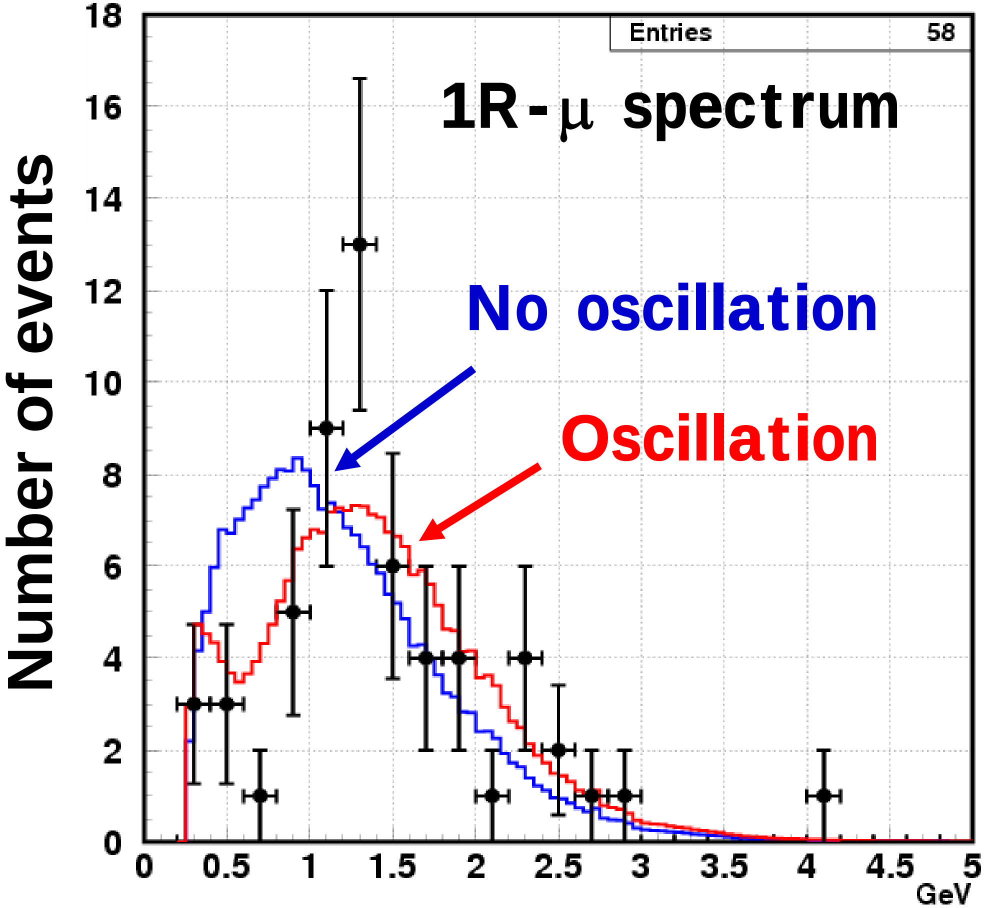
N_{sk}^{obs} systematics ~3%
- Fiducial volume 2%
- Reduction <1%
- Others <1%

N_{sk}^{pred} systematics
- Far/Near ～5%
- Normalization ～5%

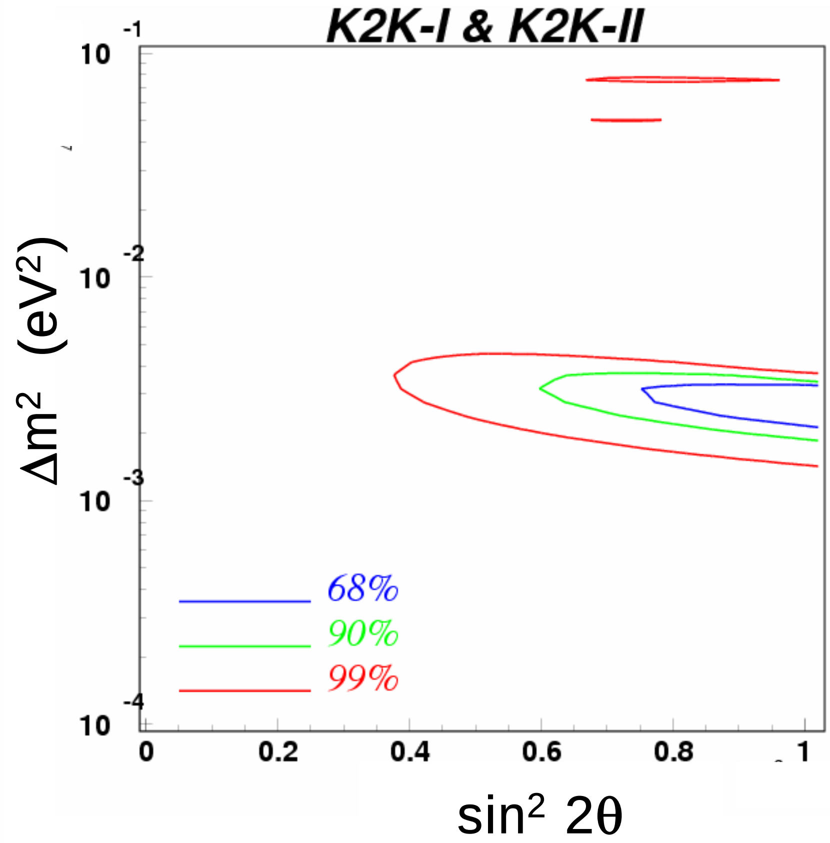
N_{sk}^{obs} Spectrum syst. (1 ring μ)
(dependent on the energy bin)
- Ring counting ~3~5%
- Fiducial volume 2%
- Particle Id <1%
- Energy scale ~2%

Energy Spectrum / Oscillation Analysis

Maximum likelihood:
L = L(#events) x L(spectrum) x L(syst. error parameters)



E_ν^{rec} (GeV)



Results of the fit

Best fit value

(all region)

$\sin^2 2\theta = 1.19 \pm 0.23$

$\Delta m^2 = (2.55 \pm 0.40) \times 10^{-3} eV^2$

(in physical region)

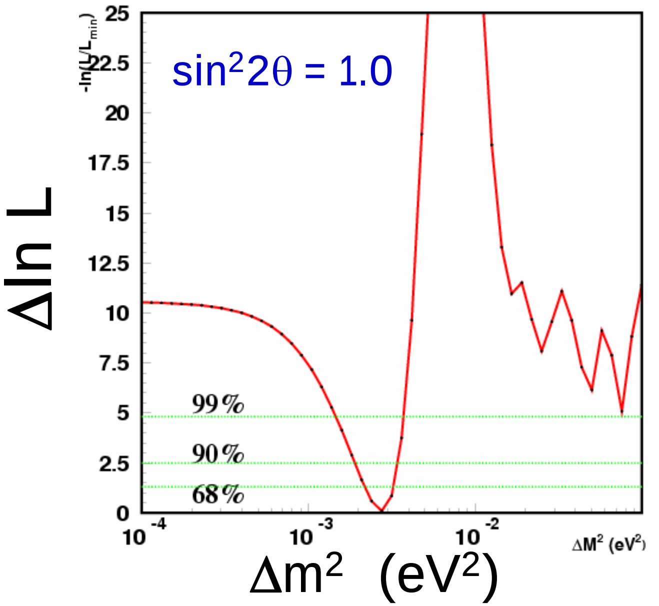
$\sin^2 2\theta = 1.0$

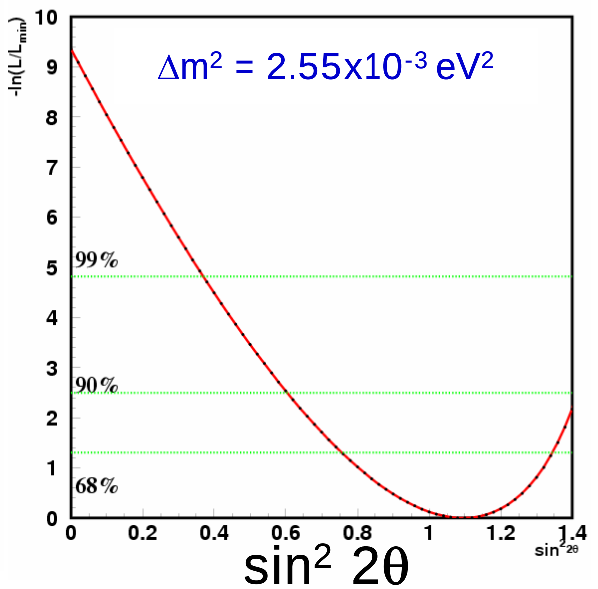
$\Delta m^2 = (2.76 \pm 0.36) \times 10^{-3} eV^2$

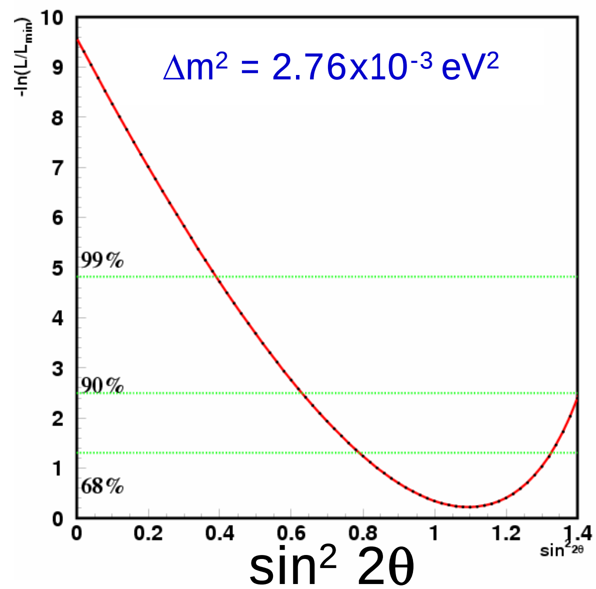
No oscillation prob.= 0.003% (4.2σ)
(for best fit in the phys. region)

$1.88 \times 10^{-3} \leq \Delta m^2 \leq 3.48 \times 10^{-3}$ eV^2
(90%CL) @ $\sin^2 2\theta = 1$

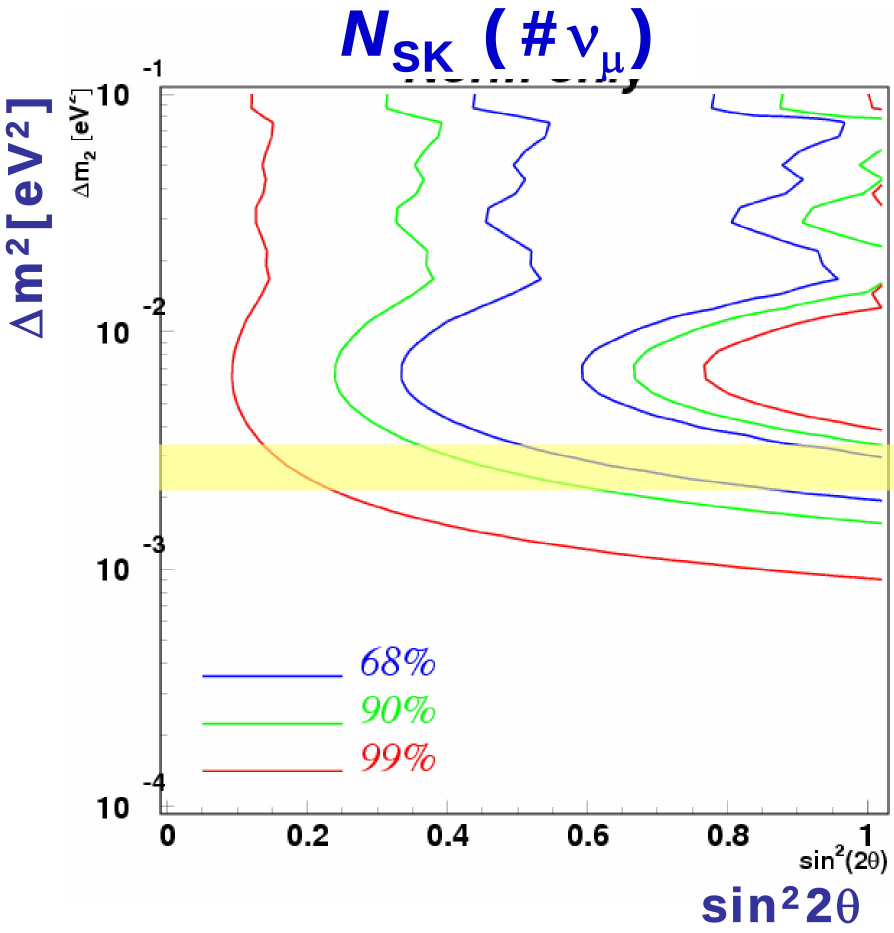
Confirmed atmospheric neutrino oscillation

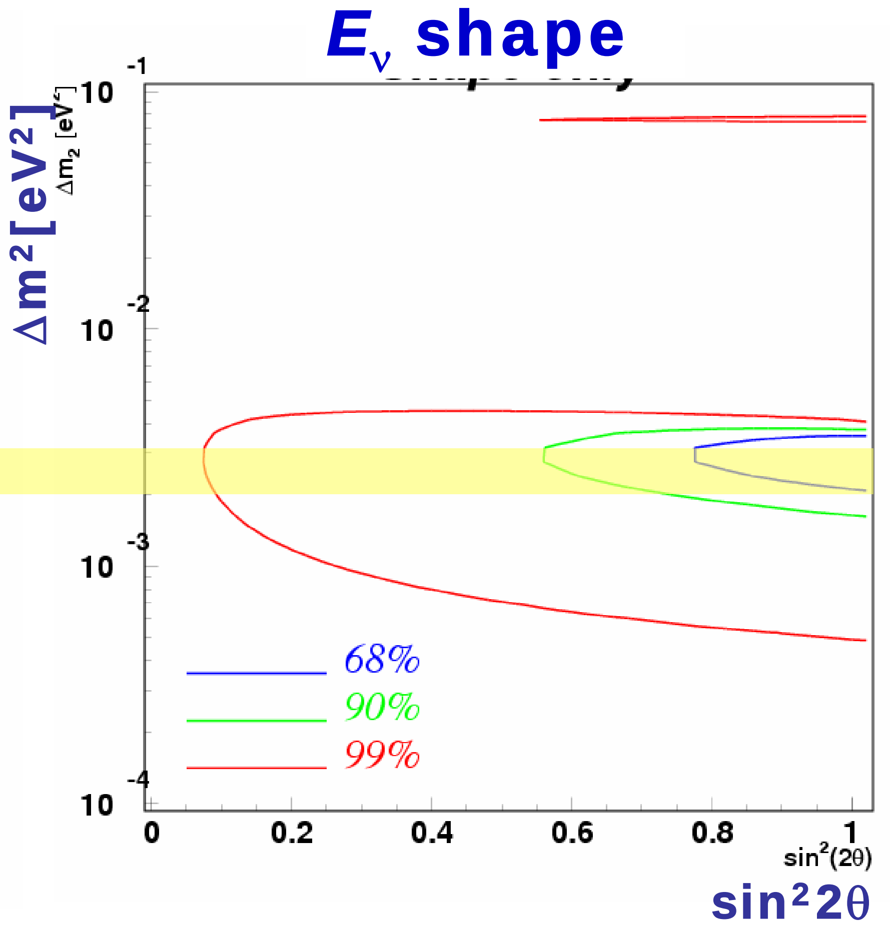






ν_μ disappearance versus E_ν shape distortion



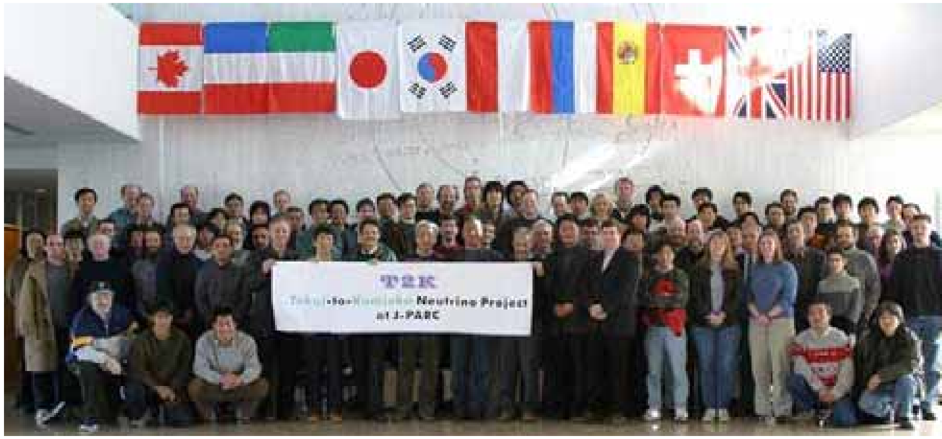


Allowed regions from ν_μ disappearance and distortion of Eν spectrum are consistent.

Other K2K results

- Search for ν_e appearance
  - PRL 93 (2004) 051801 ← K2K-1
  - Preliminary results ← K2K-I+II
- Studies of neutrino interactions
  - PLB 619 (2005) 255 ← NC π^0 production
  - hep-ex/0506008 ← coherent π suppression
  - In presparation ← Axial vector mass M_A

T2K Collaboration



- **Formed in May 2003**
- **11 countries, >50 institutions**
  >150 collaborators
- **Spokesperson: K.Nishikawa**

- **Canada**: TRIUMF, U. Alberta, York U., U. Toronto,U. Victoria, U. Regina
- **France**: CEA Saclay
- **Italy**: U. Roma, U. Bari, U. Napoli, U. Padova
- **Japan**: ICRR, KEK, Tohoku U., Hiroshima U., Kyoto U., Kobe U., Osaka City U., U. Tokyo, Okayama U., Miyagi U. of Education
- **Korea**: Seoul National U., Chonnam National U., Dongshin U., Kangwon U., Kyungpook National U., KyungSang National U.,SungKyunKwan U., Yonsei U.
- **Poland**: Warsaw U.
- **Russia**: INR
- **Spain**: U. Barcelona, U. Valencia
- **Switzerland**: U. Geneva, (ETH Zurich)
- **UK**: RAL, Imperial College London, Queen Mary, Westfield College London, U. Liverpool
- **USA**: UCI, SUNY-SB, U. Rochester, U. Pennsylvania, Boston U., CSU, Duke, Dominguez Hills, BNL, UCB/LBL, U. Hawaii, ANL, MIT, LSU, LANL, U. Washington

This list is obsolete.
Collaboration is expanding.

Neutrino mixing: formulation

- MNS matrix

$$U = O_{23}\,\Gamma_\delta\, O_{13}\,\Gamma_\delta^\dagger\, O_{12}$$

- where

$$O_{23} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix},\quad O_{13} = \begin{pmatrix} c_{13} & 0 & s_{13} \\ 0 & 1 & 0 \\ -s_{13} & 0 & c_{13} \end{pmatrix},\quad O_{12} = \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$$\Gamma_\delta = \mathrm{diag}(1, 1, e^{i\delta})$$

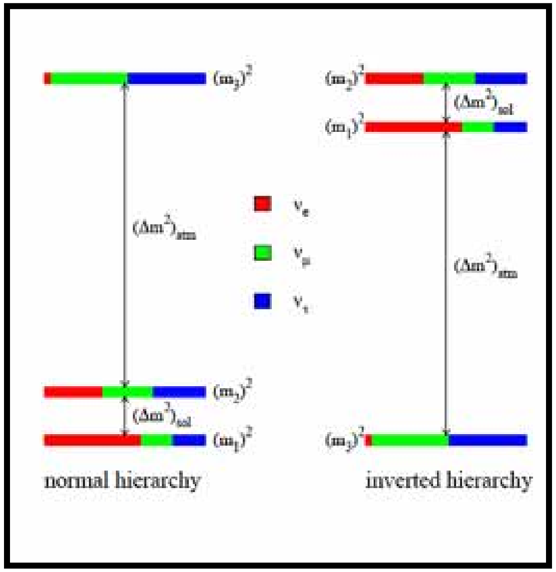
- Explicit form of U

$$U = \begin{pmatrix} c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta} \\ -s_{12}c_{23} - c_{12}s_{13}s_{23}e^{i\delta} & c_{12}c_{23} - s_{12}s_{13}s_{23}e^{i\delta} & c_{13}s_{23} \\ s_{12}s_{23} - c_{12}s_{13}c_{23}e^{i\delta} & -c_{12}s_{23} - s_{12}s_{13}c_{23}e^{i\delta} & c_{13}c_{23} \end{pmatrix}$$

- For Majorana neutrinos

$$U \to U \cdot U_M\,, \quad U_M = \mathrm{diag}(e^{\frac{i}{2}\alpha_1}, e^{\frac{i}{2}\alpha_2}, 1)$$

- Parameters in the neutrino mass and mixing matrices
  - 3 masses: m_1, m_2, m_3
  - 3 mixing angles: θ_{12}, θ_{23}, θ_{13}
  - 1 CP violating phase in the mixing matrix: δ
  - 2 Majorana phases: α_1, α_2



- Neutrino oscillations are sensitive to:
  - 2 mass squared differences
    - $\Delta m_{21}^2 = m_2^2 - m_1^2 = m_{solar}^2$
    - $\Delta m_{32}^2 = m_3^2 - m_2^2 = m_{atm}^2$

      $(\Delta m_{21}^2 + \Delta m_{32}^2 + \Delta m_{13}^2 = 0)$
  - 3 mixing angles: θ_{12}, θ_{23}, θ_{13}
  - 1 CP violating phase in the mixing matrix: δ

T2K-I

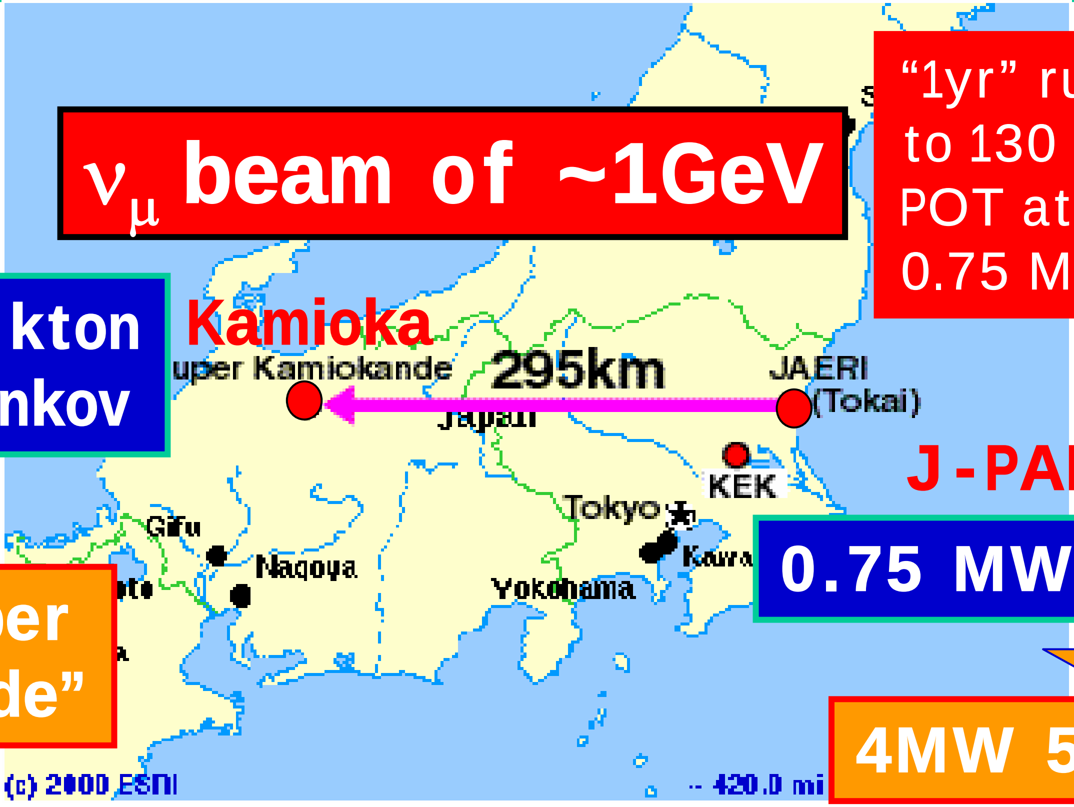
T2K-II

Overview of the T2K Experiment

A word of warning: T2K-II ≠ J-PARC Phase II, rather beyond J-PARC Phase II

ν_μ beam of ~1GeV

"1yr" run corresponds to 130 days, or 10^{21} POT at 50 GeV with 0.75 MW beam power.



Kamioka

J-PARC

Super-K: 50 kton Water Cherenkov

~Mt "Hyper Kamiokande"

0.75 MW 50 GeV PS

4MW 50 GeV PS

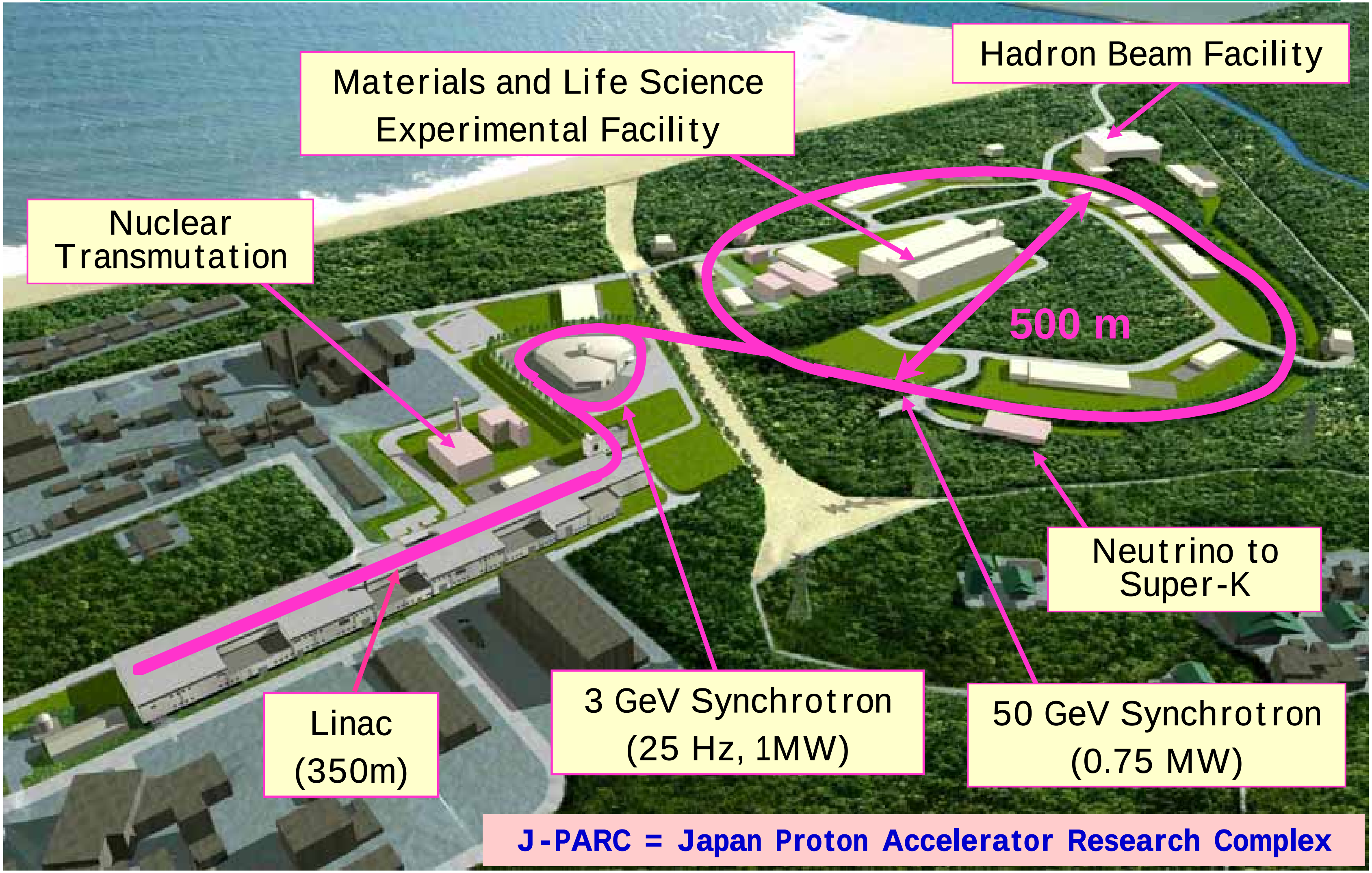
1st Phase

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

Future

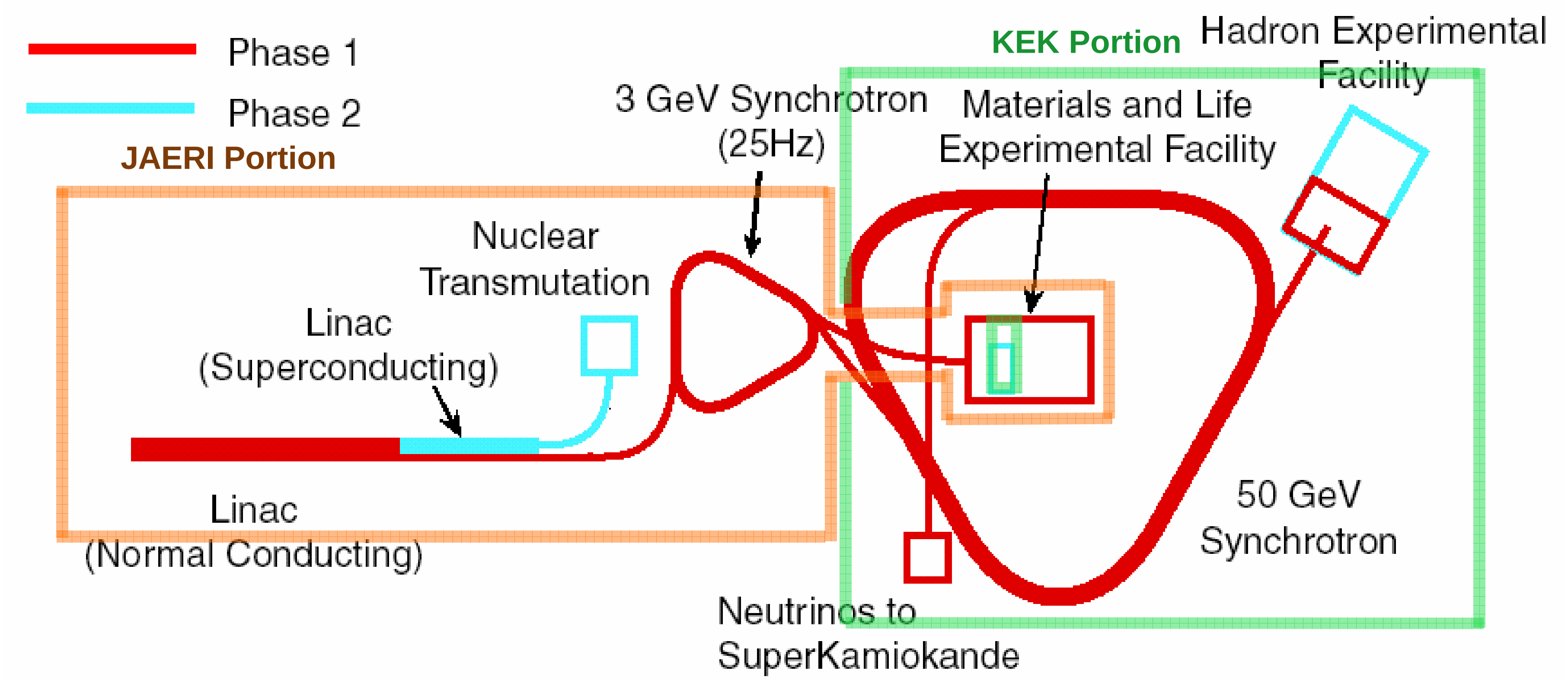
- **CPV**
- **proton decay**

J-PARC Facility



Joint Project between KEK and JAERI

J-PARC Phase 1 and Phase 2



Phase 1 + Phase 2 = 1,890 Oku Yen (= $1.89 billions if $1 = 100 Yen)

Phase 1 = 1,527 Oku Yen (= $1.5 billions) for 7 years

JAERI: 860 Oku Yen (56%), KEK: 667 Oku Yen (44%).

J-PARC Phase I: Under Construction

Accelerator Facility: JFY 2001 – 2007

Initially, LINAC: 180 MeV (to be upgraded to 400 MeV in a few years)

Main ring: 40 GeV (to be upgraded to 50 GeV in Phase-II)

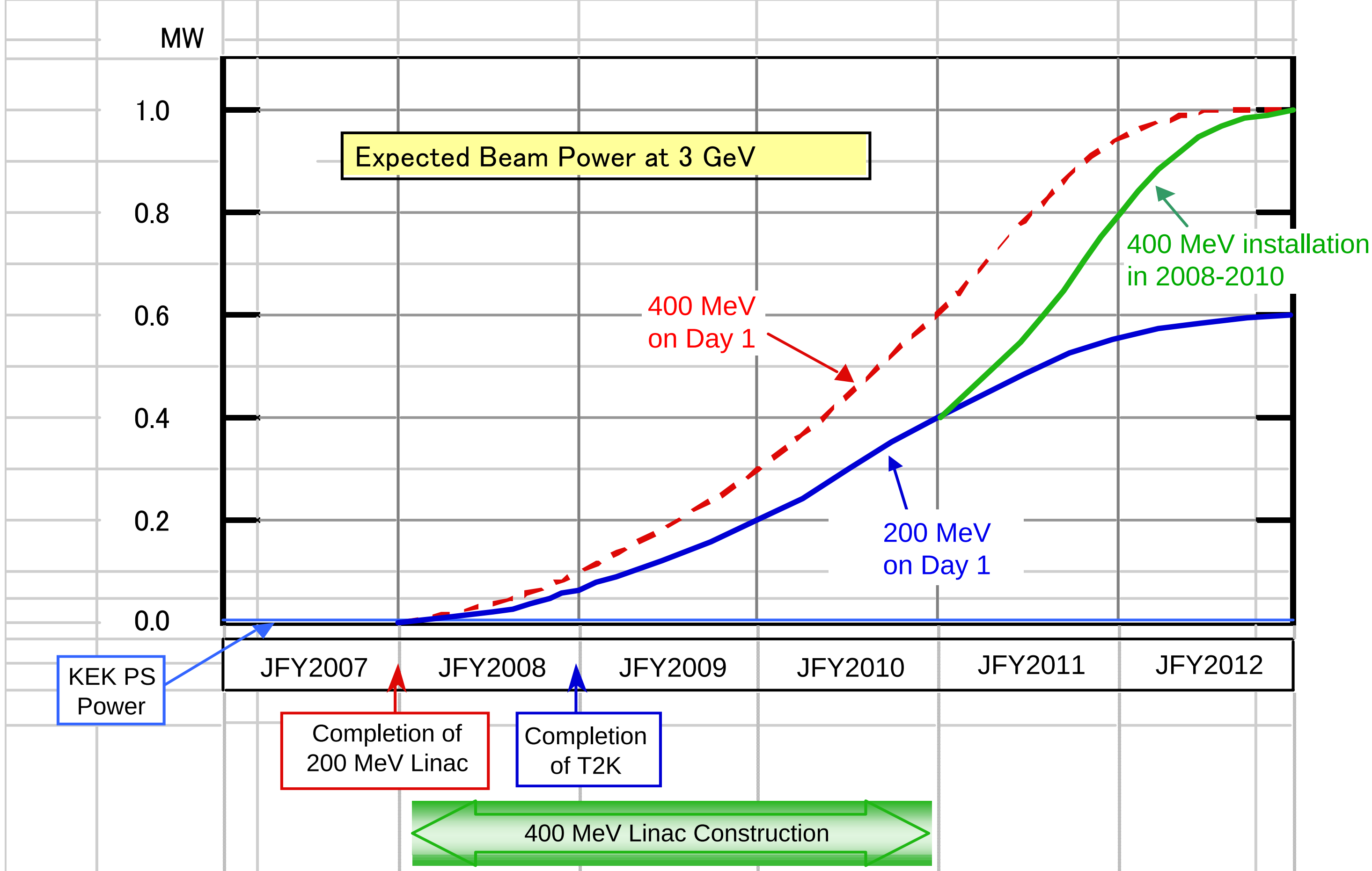
Hadron Facility: JFY 2003 – 2007

Neutrino Facility: JFY 2004 - 2008

December 2003

January, 2005

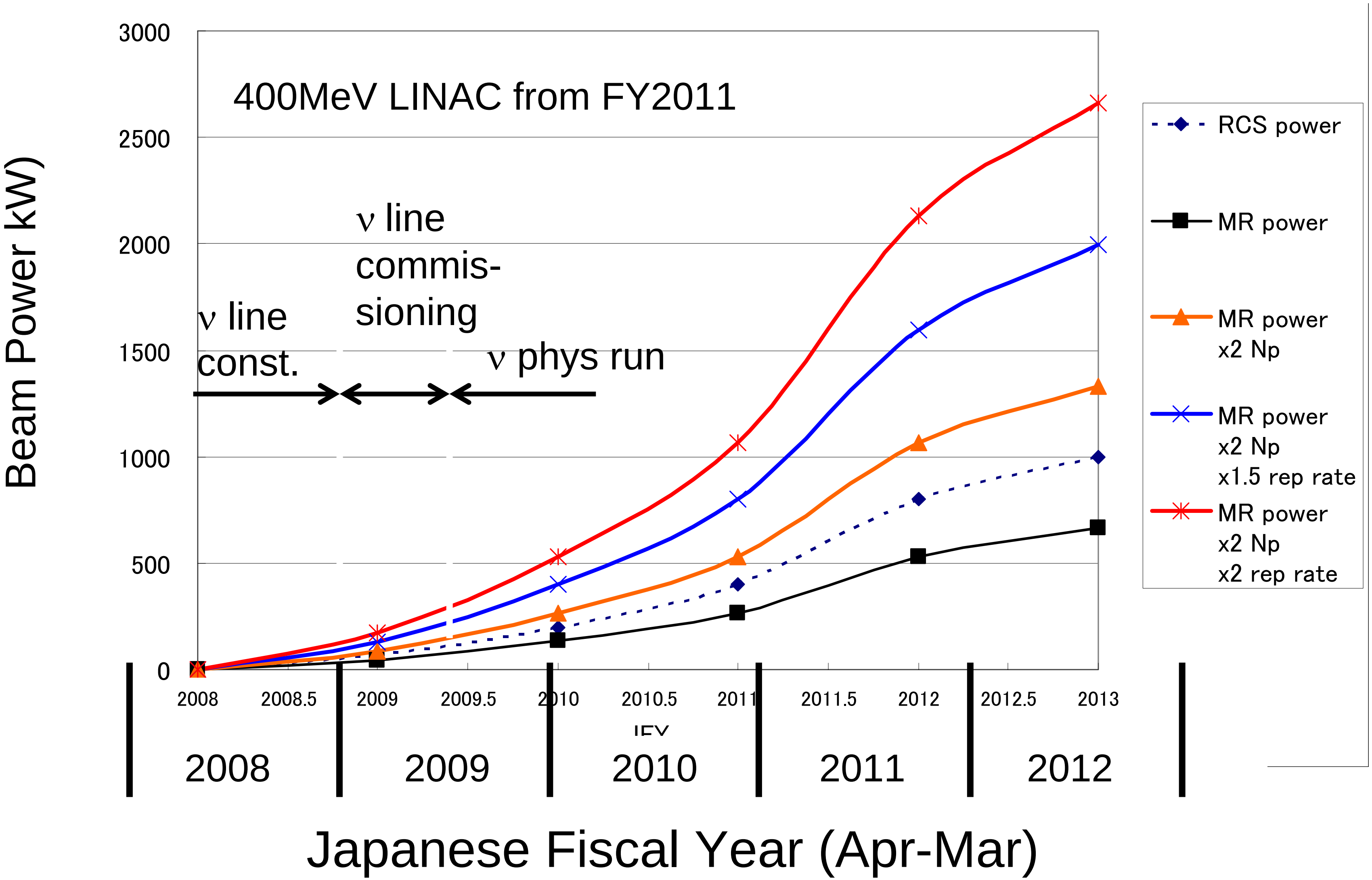
Schedule for LINAC Energy Recovery and Expected Beam Power of 3 GeV RCS



	JFY2007	JFY2008	JFY2009–JFY2012
3 GeV Neutron and Muon	Construction	Beam Test	Usage for Experiments
50 GeV Nuclear - Particle	Construction	Usage for Experiments	
T 2 K Experiment	Construction		Usage for Experiment

K

Possibility of beam power upgrade for a fast extracted beam from the main ring at 30 – 40 GeV



Neutrino Facility

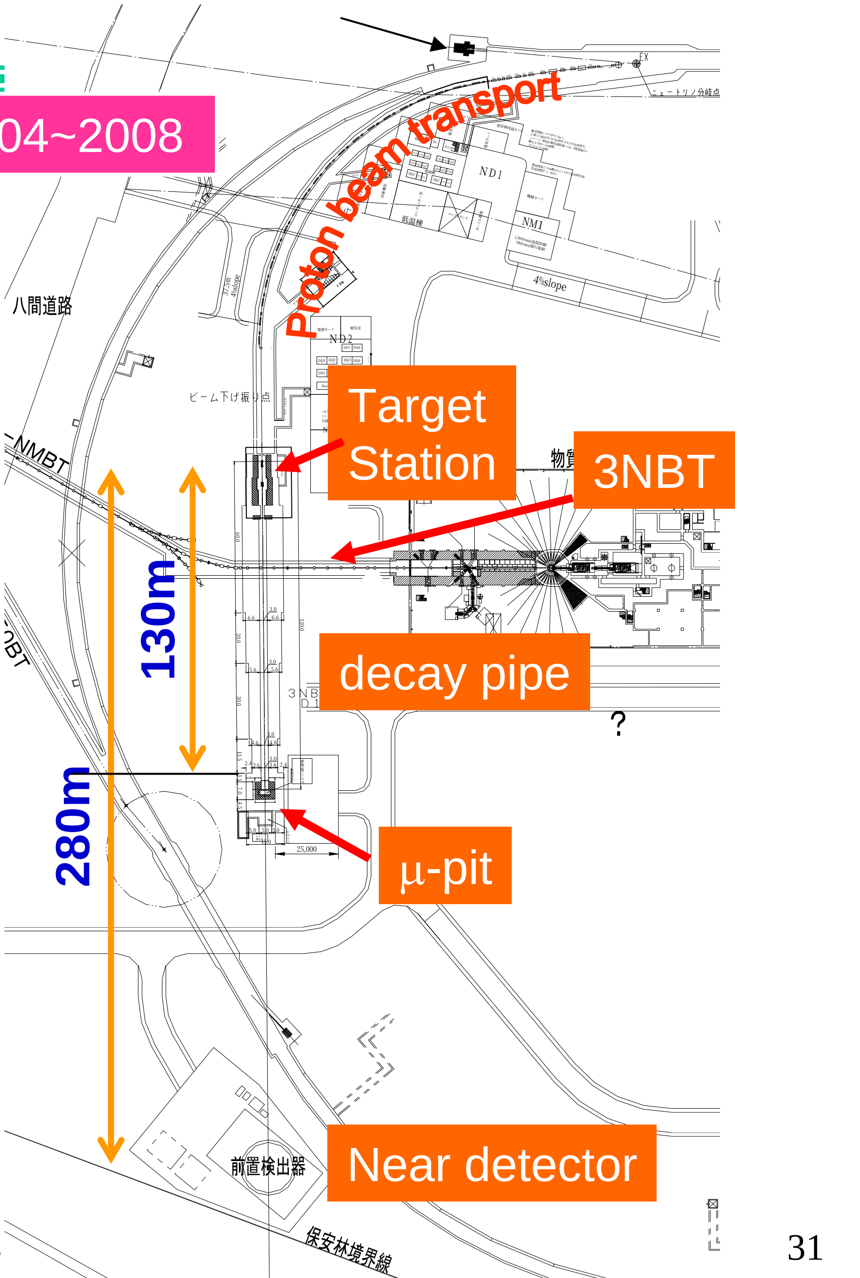
Components

Construction: JFY2004~2008

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

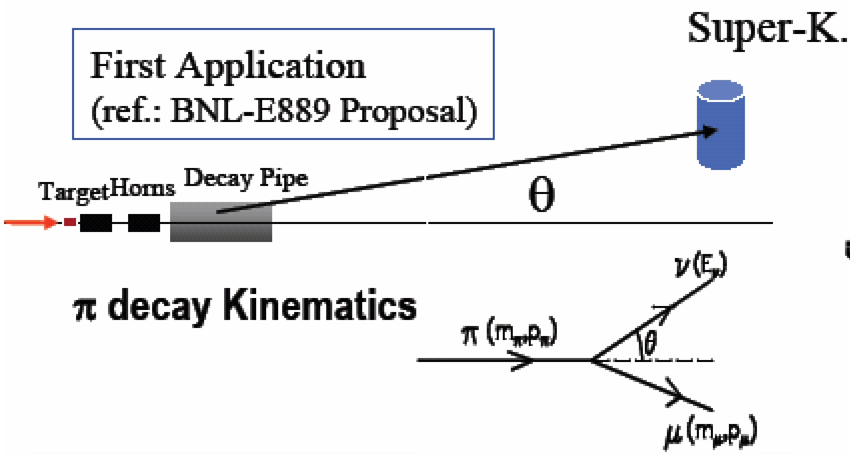
Special Features

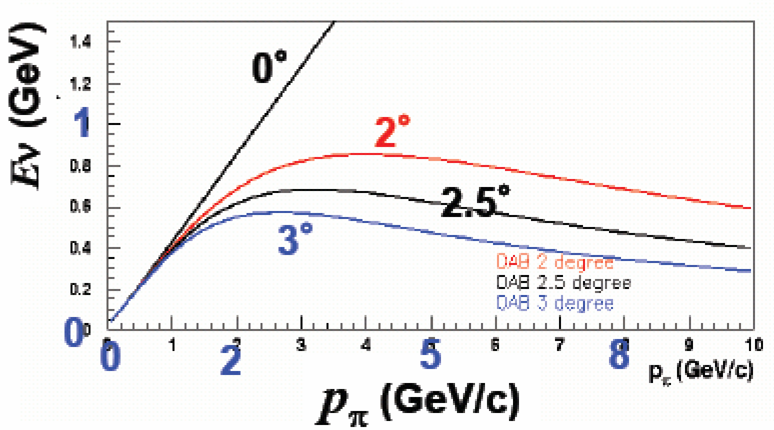
- Superconducting combined function magnets
- **Off-axis beam**

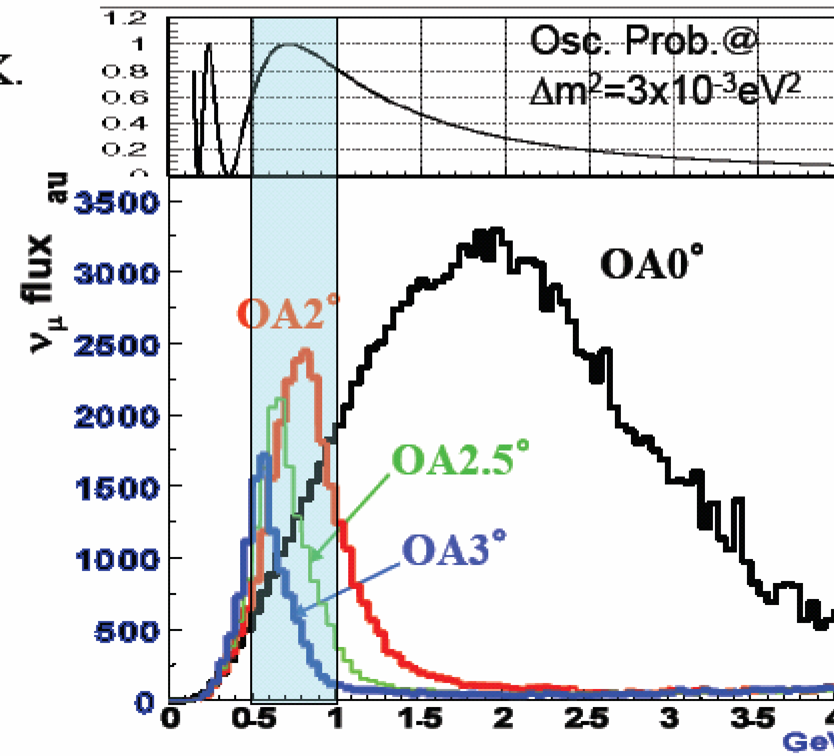


Narrow Intense Beam: Off-Axis Beam

First Application
(ref.: BNL-E889 Proposal)







- **Quasi Monochromatic Beam**
- **x 2~3 intense than NBB**
- **Tuned at oscillation maximum**

Statistics at SK

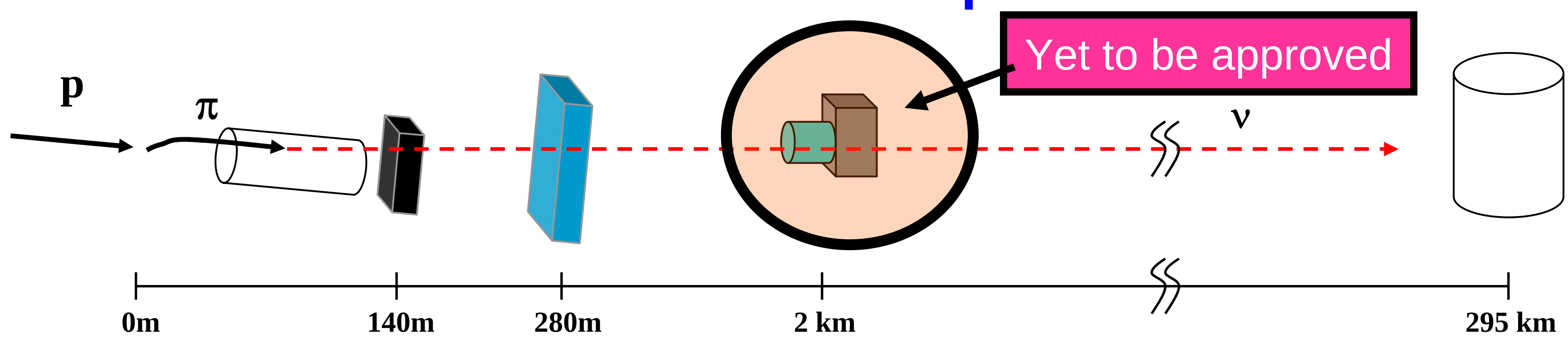
(OAB 2.5 deg, 1 yr, 22.5 kt)

~ 2200 ν_μ tot

~ 1600 ν_μ CC

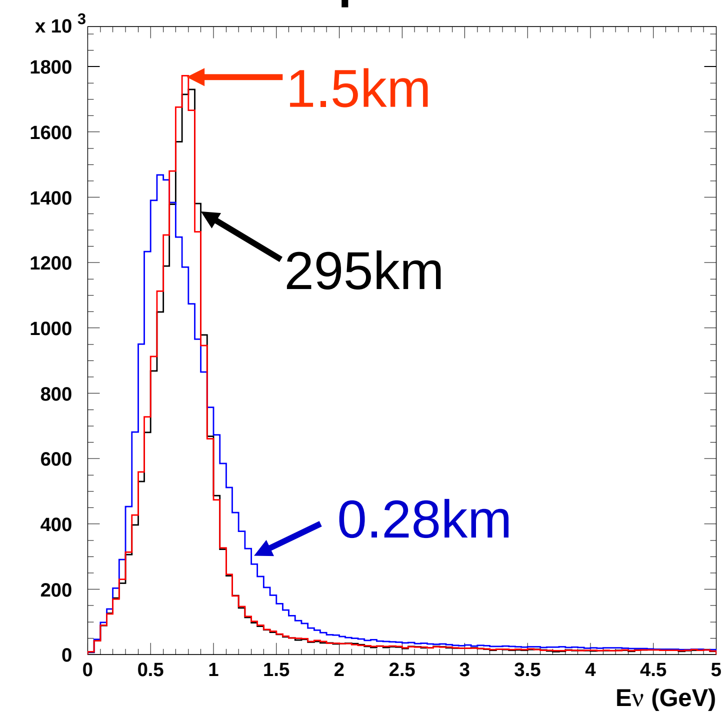
ν_e ~0.4% at ν_μ peak

Detector Complex



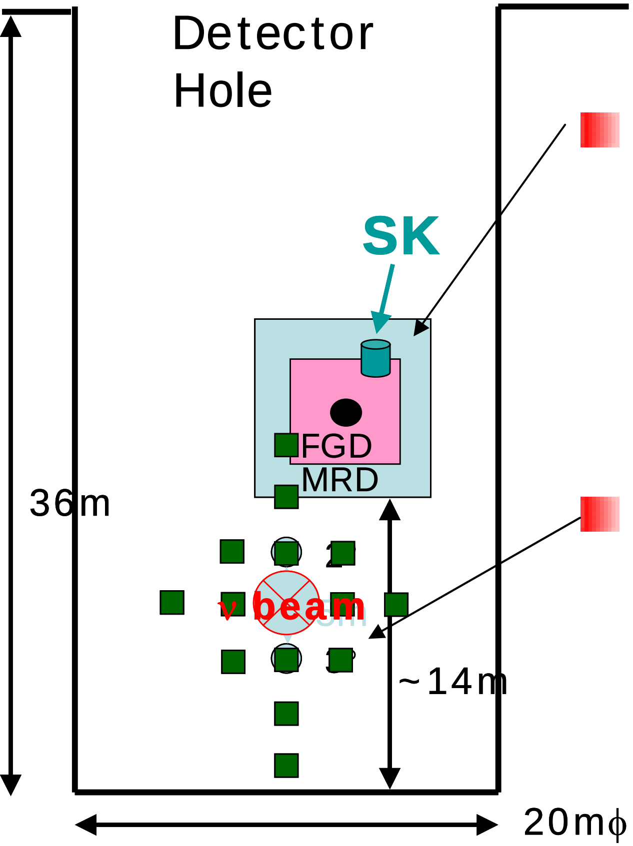
- **Muon monitors @ ~140m**
  - Fast (spill-by-spill) monitoring of beam direction/intensity
- **First near detector @280m**
  - Flux/spectrum/νe
  - intensity/direction
- **Second near detector @ ~2km**
  - Almost same E_ν spectrum as for SK
  - Water Cherenkov can work
- **Far detector @ 295km**
  - **Super-Kamiokande (50kt)**

Neutrino spectra at diff. dist



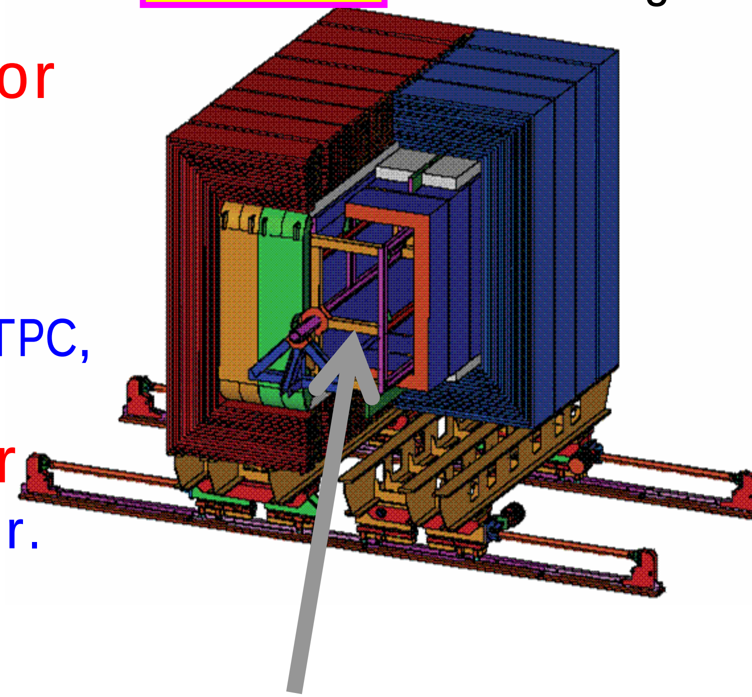
dominant syst. in K2K

Conceptual Design of Near Detector @ 280m



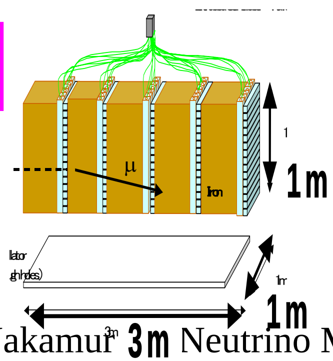
Off-axis

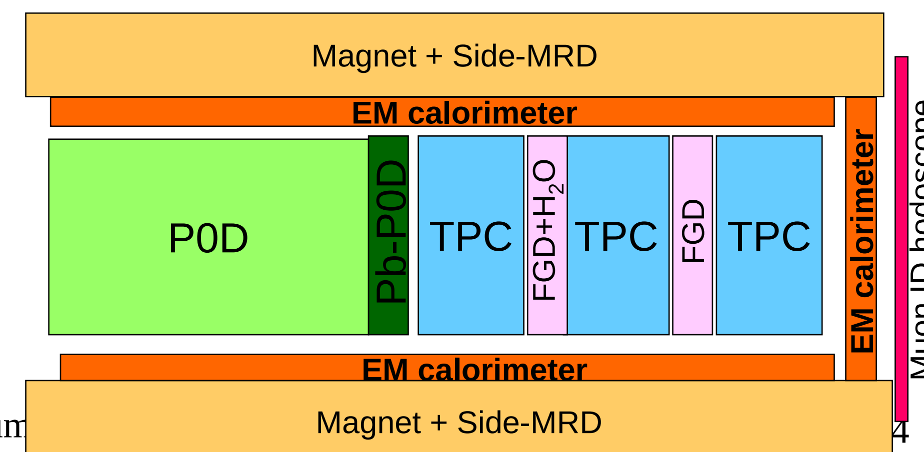
UA1 mag



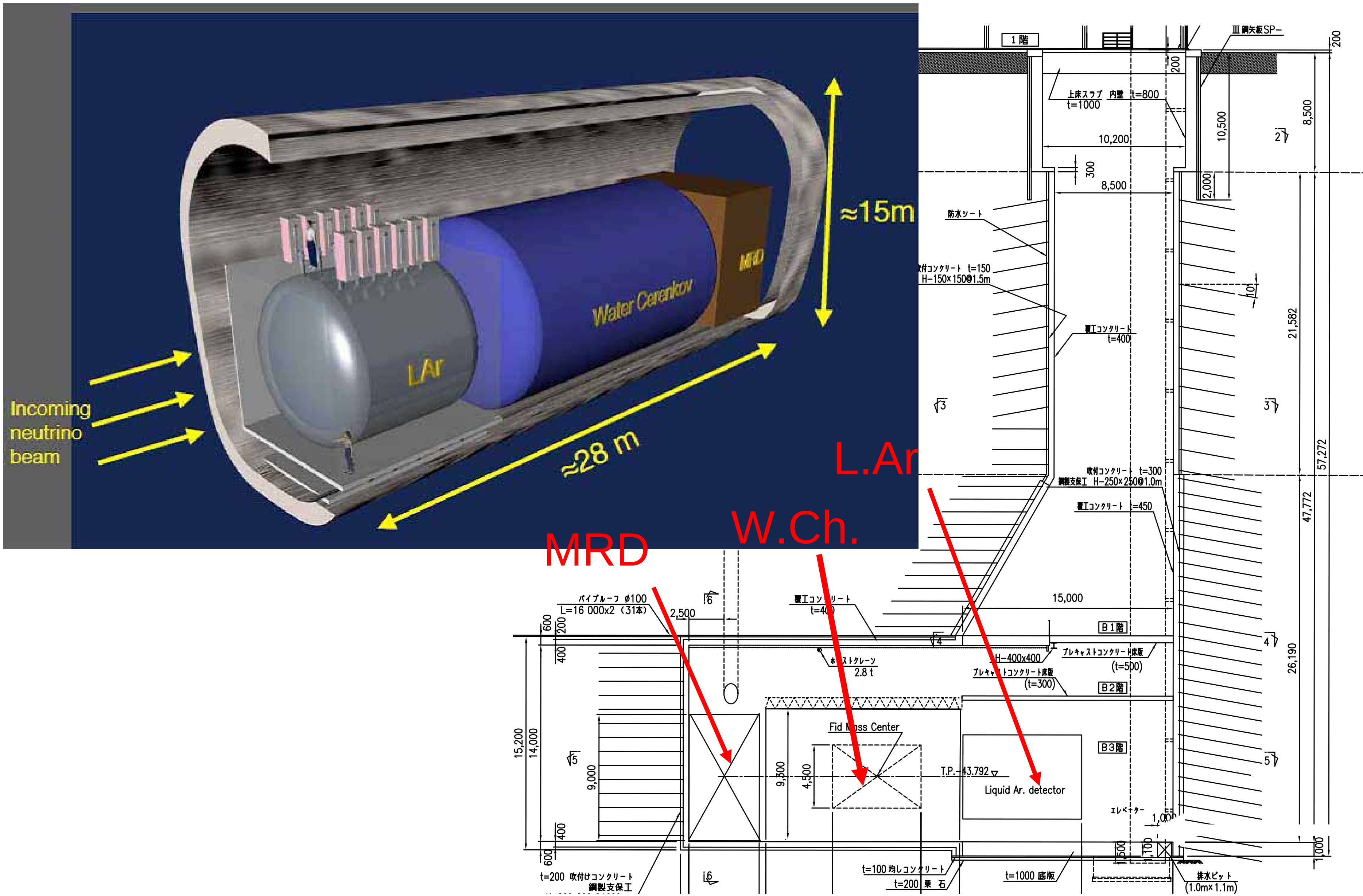
- Off-axis detector
  - ν spectrum
  - Cross sect.
  - ν_e contami.
  - UA1 mag, FGD, TPC, Ecal,..
- On axis detector
  - Monitor beam dir.
  - Grid layout

On-axis





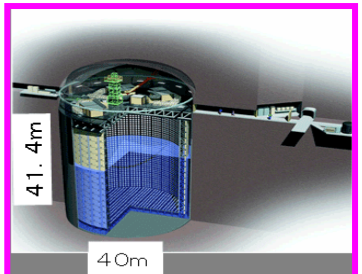
Conceptual Design of 2km Detector

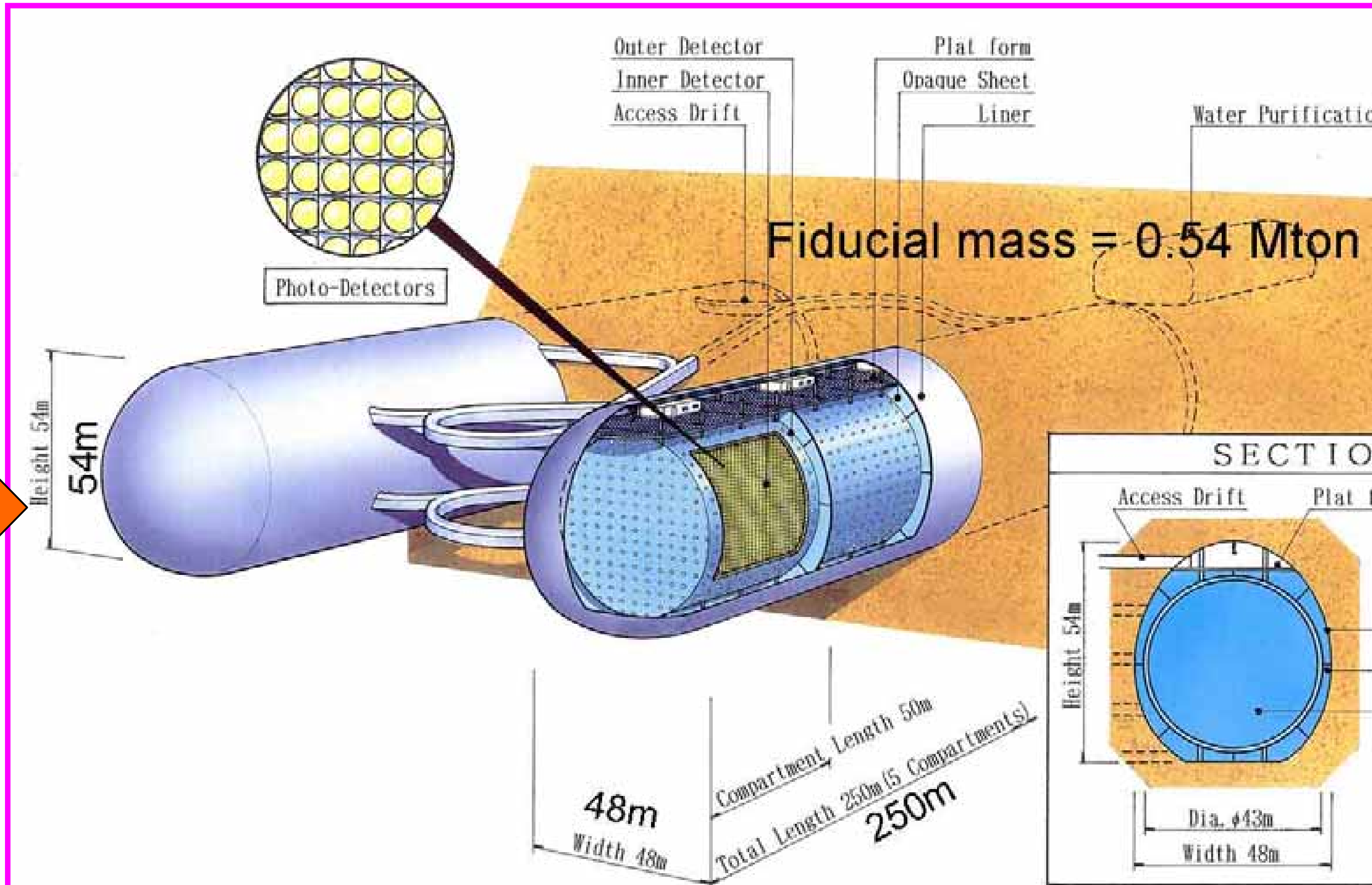


Far Detectors

1st Phase (2009~, ≥5yrs)
Super-Kamiokande(22.5kt)

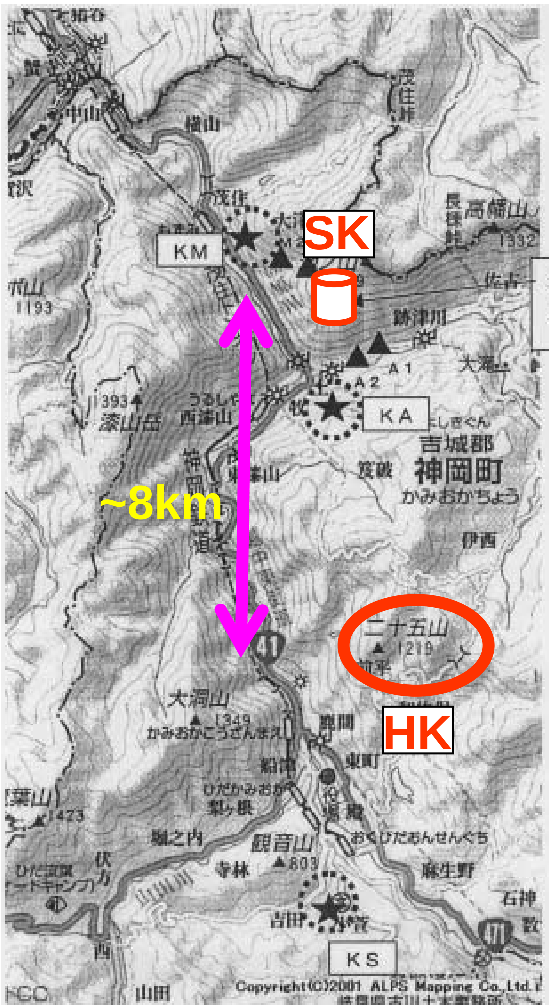
Future (201x~?)
Hyper-Kamiokande(~540kt)





Common Decay Pipe for SK/HK Covering 2~3 deg OA Angle

Candidate site for HK



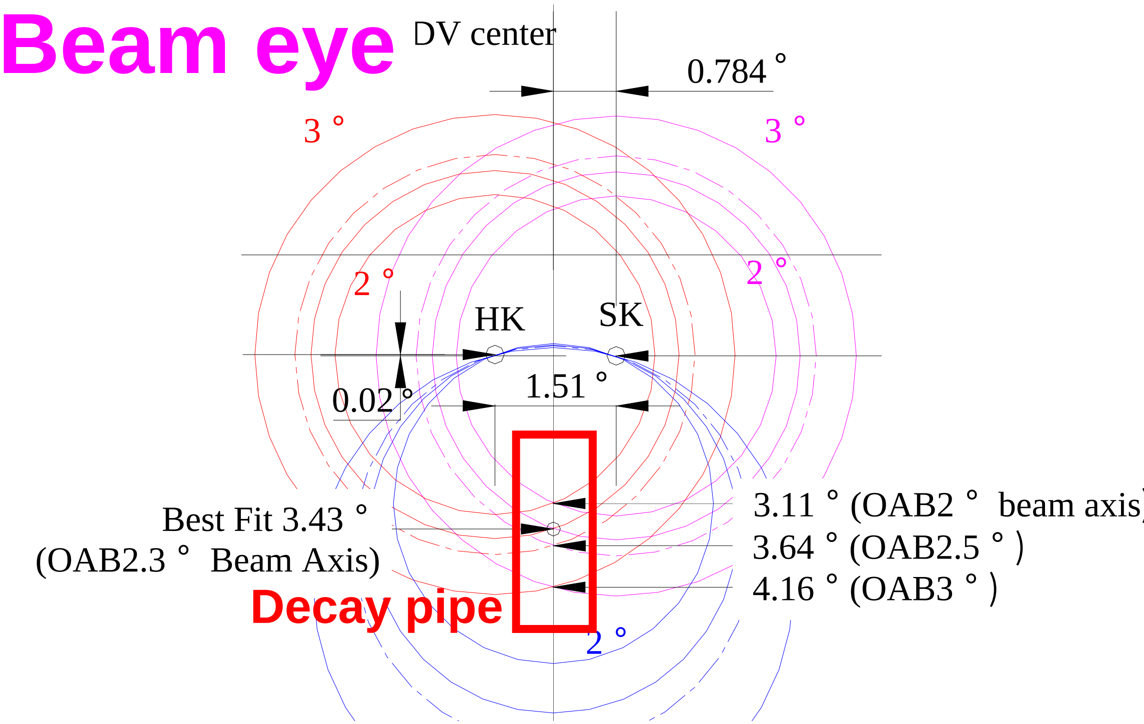
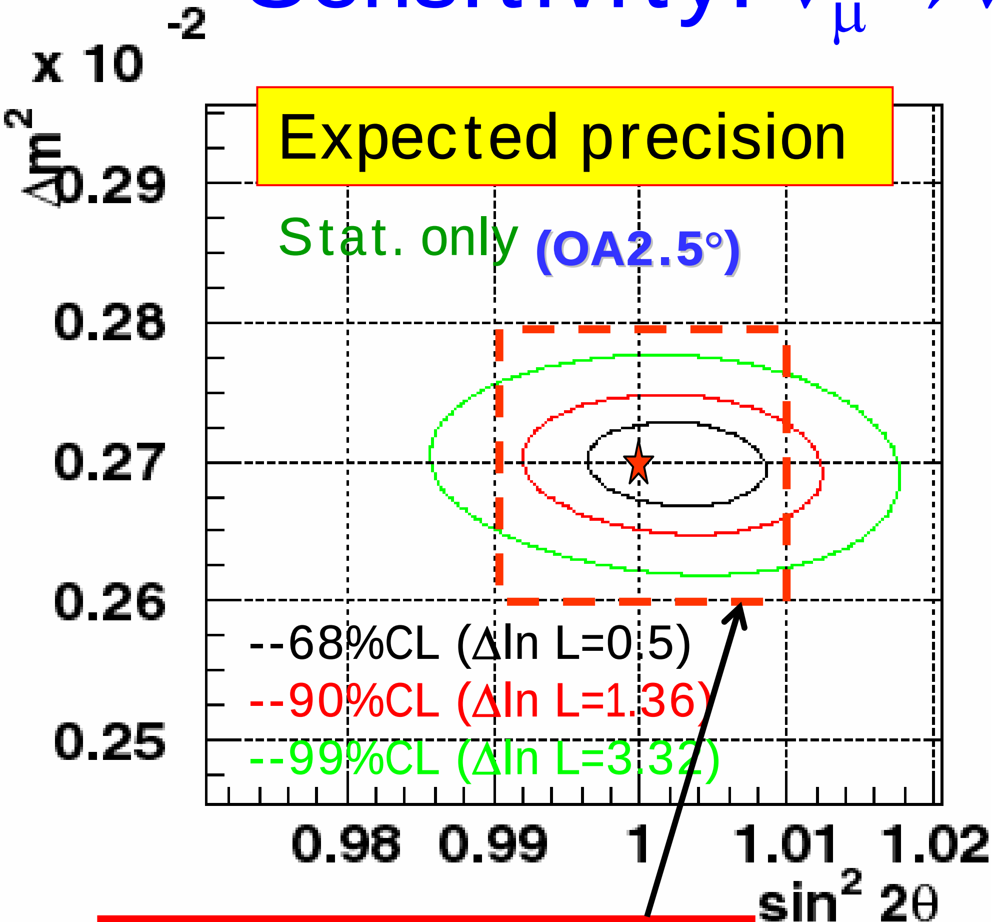


表 3.1: E_ν at the oscillation maximum for the baseline length of 295km and corresponding off-axis angle.

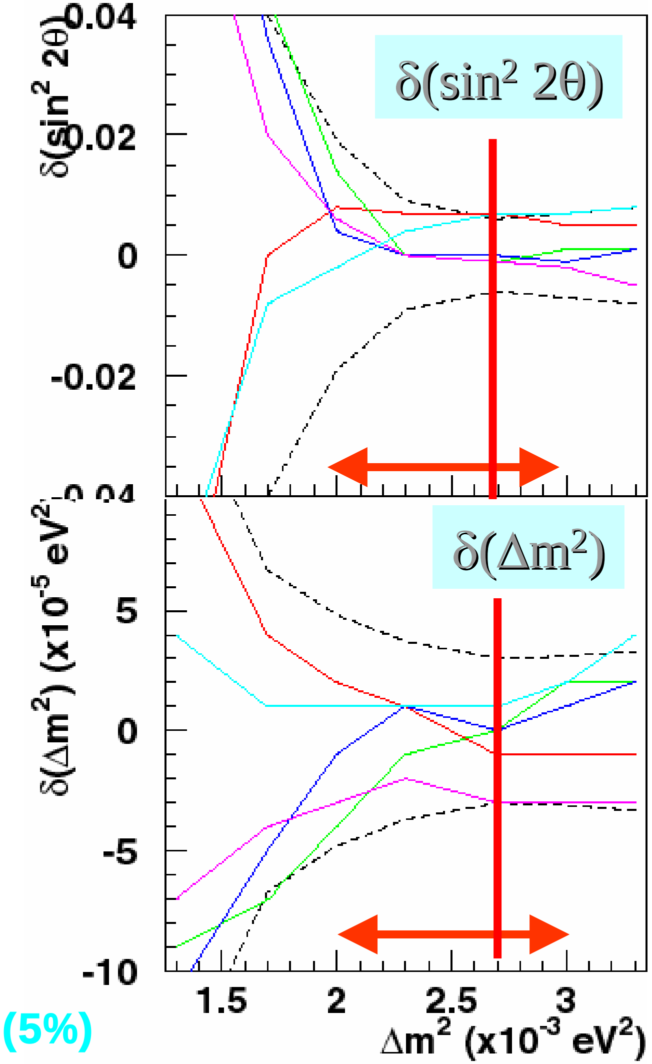
Δm^2 $[10^{-3}eV^2]$	2.04 (90% A.R.)	2.18 (80% A.R.)	2.75 (best fit)	3.17 (80% A.R)	3.28 (90 % A.R)
$E_\nu[GeV]$	0.487	0.520	0.656	0.756	0.782
OA angle[deg.]	3.1	3.0	2.4	2.1	2.0

$\underbrace{3.0 \quad 2.4 \quad 2.1 \quad 2.0}_{\text{Cover this region}}$

Sensitivity: $\nu_\mu \rightarrow \nu_\mu$ Disappearance



Effect of systematic error on param meas.



Goal

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

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

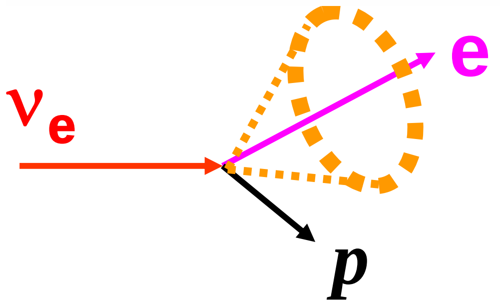
Stat. error

norm (+5%)
NQE (+5%)
E_{SK} (+1%)
spectrum shape ($\pm$20%)
Spectrum width (5%)

Sensitivity: ν_e Appearance

Measurement of ν_e appearance (θ_{13},Δm_{13})

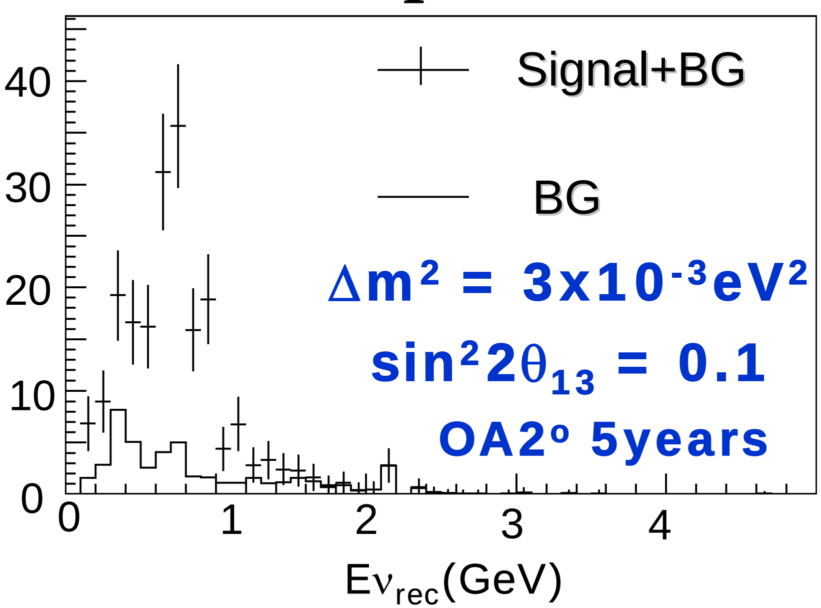
$$P_{\mu\to e} \approx \sin^2\theta_{23}\cdot\sin^2 2\theta_{13}\cdot\sin^2\left(1.27\,\Delta m_{13}^2 L/E_\nu\right)$$

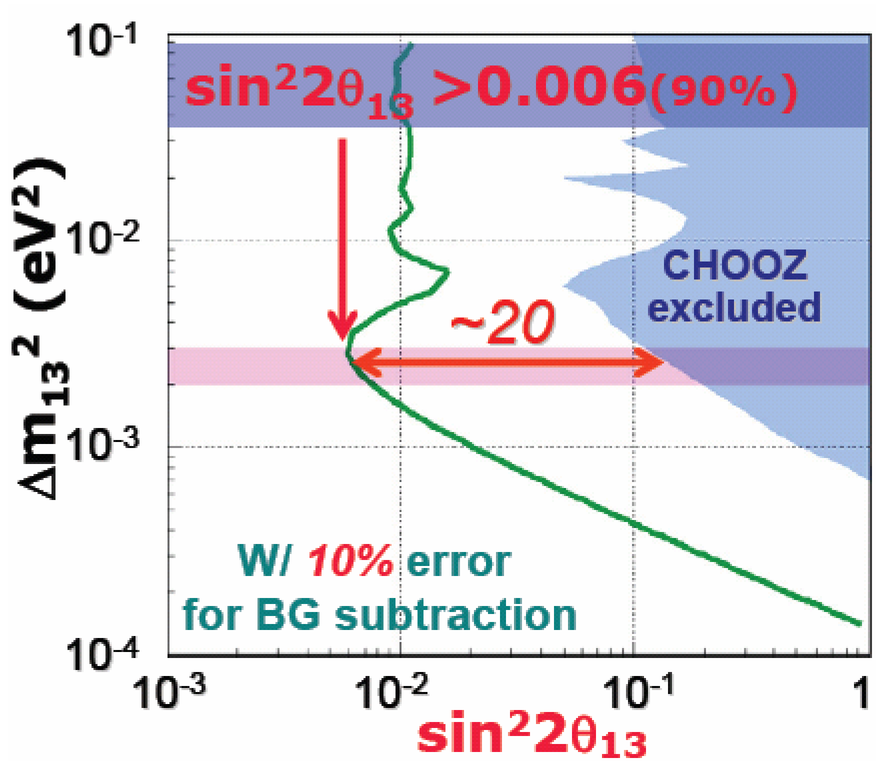


(P_e, θ_e)

↓

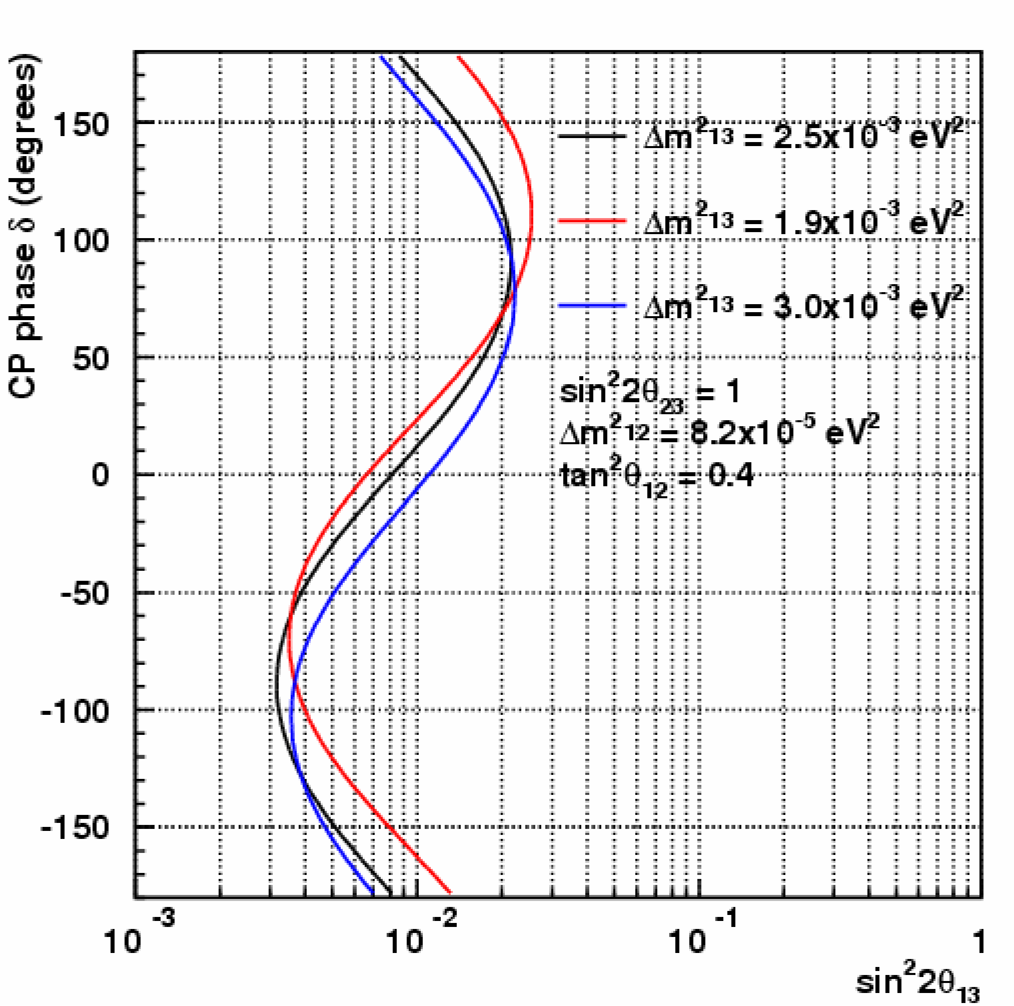
E_ν





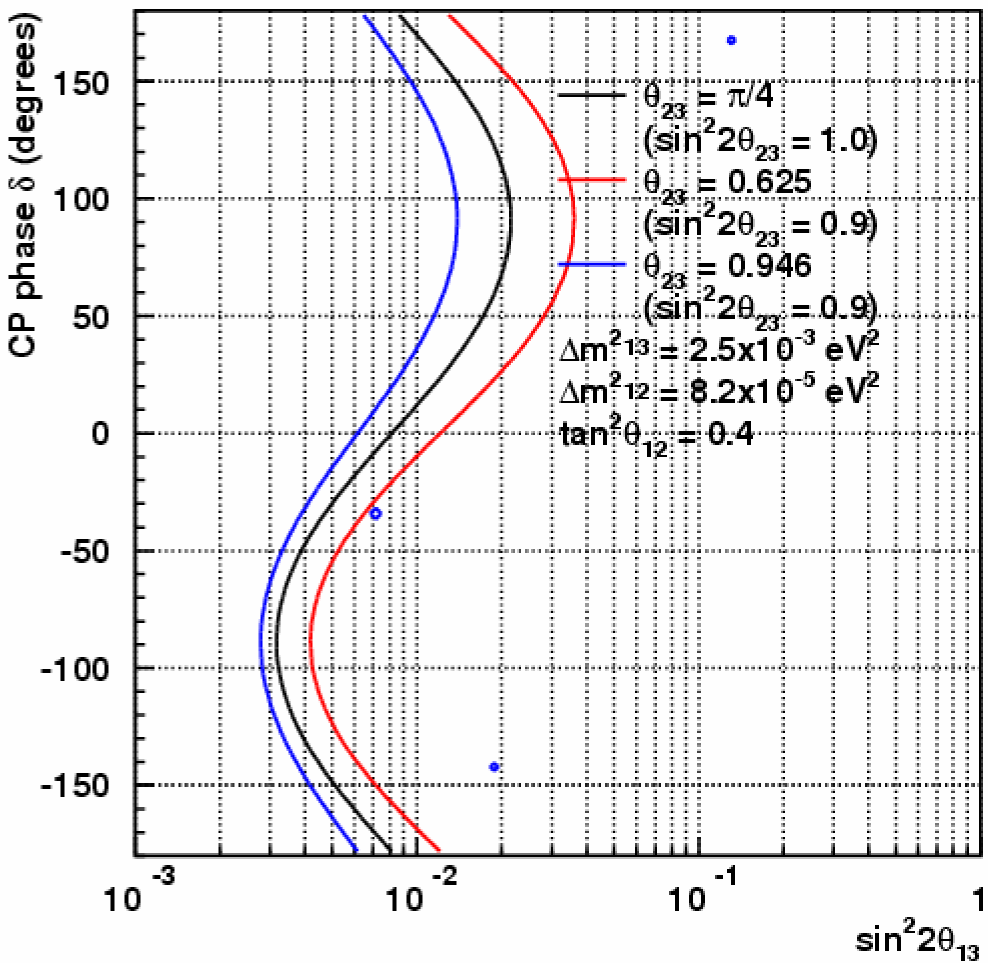
Assuming $\sin^2\theta_{23}$=0.5, δ=0, no matter

Sensitivity as a function of δ for different values of the atmospheric splitting



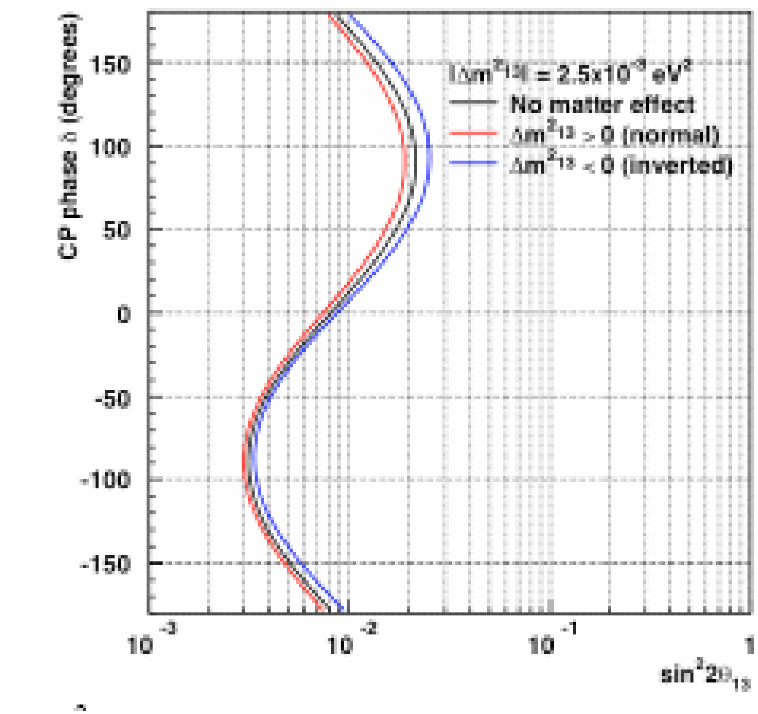
- 40 GeV
- 10^{21} POT/yr
- 5 years

Sensitivity as a function of d for different values of $\sin^2 2\theta_{23}$



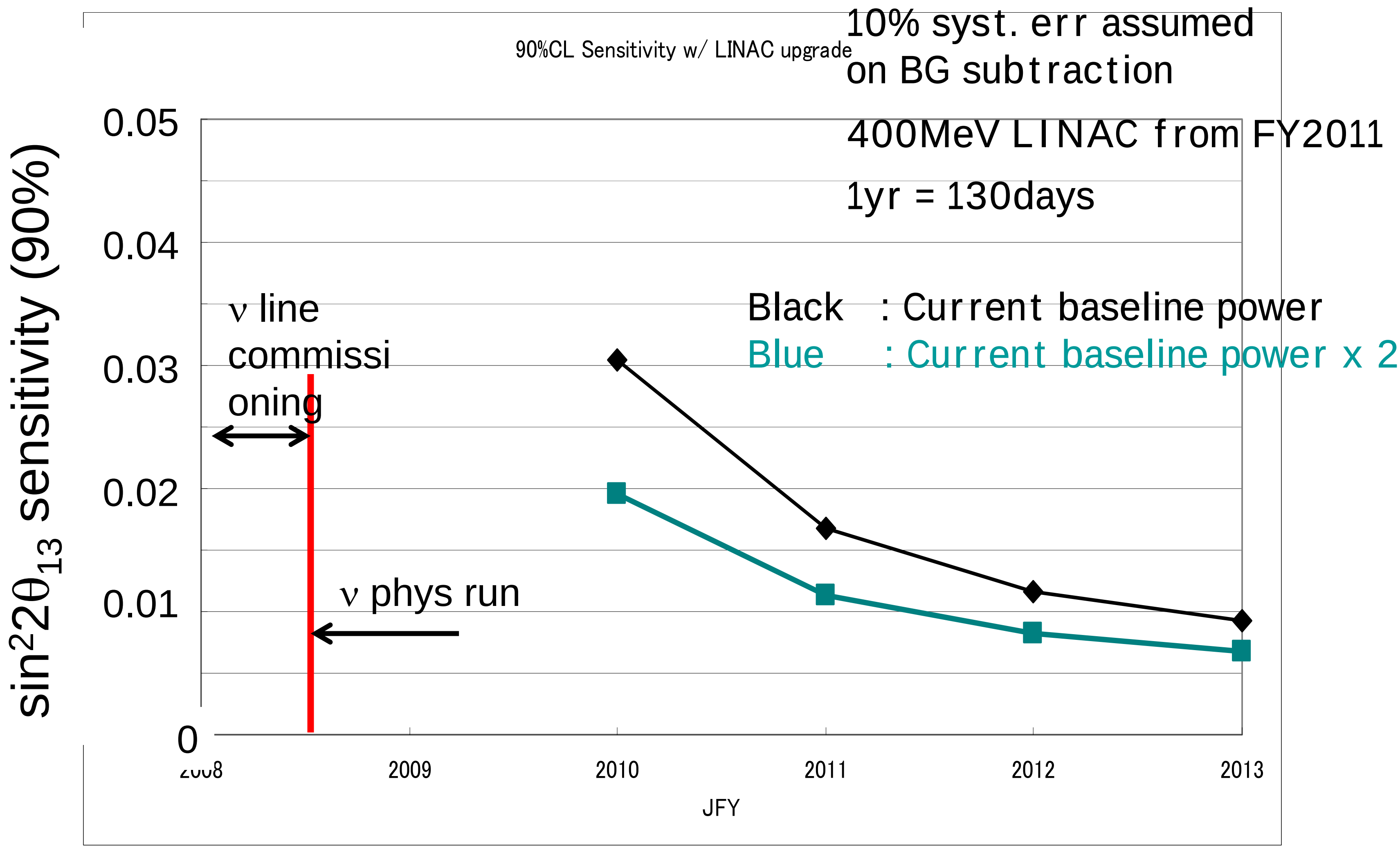
- 40 GeV
- 10^{21} POT/yr
- 5 years

Sensitivity as a function of δ for normal and inverted mass hierarchies

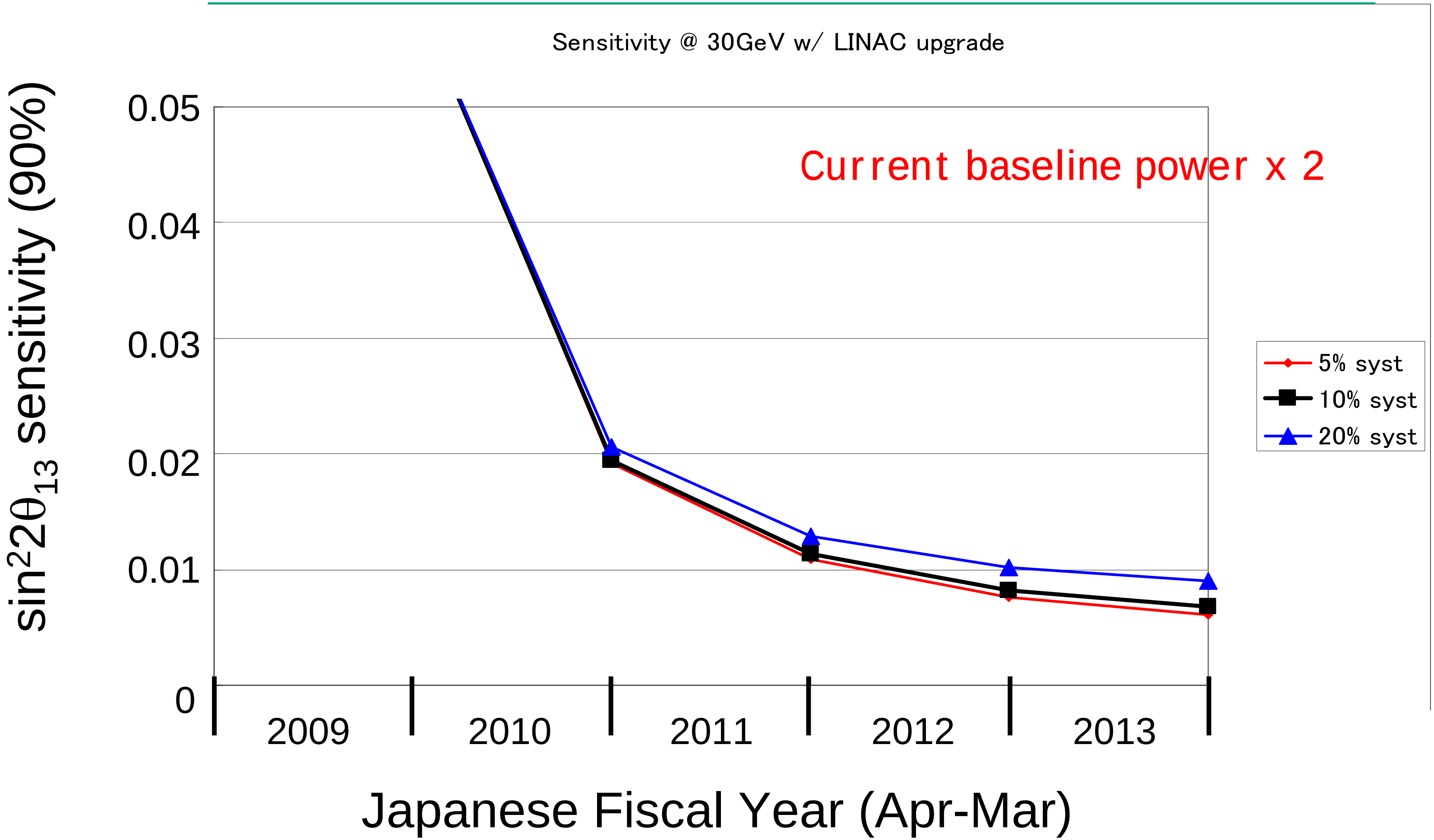


- 40 GeV
- 10^{21} POT/yr
- 5 years

Expected sensitivity improvement as a function of time (1)



Expected sensitivity improvement as a function of time (2)

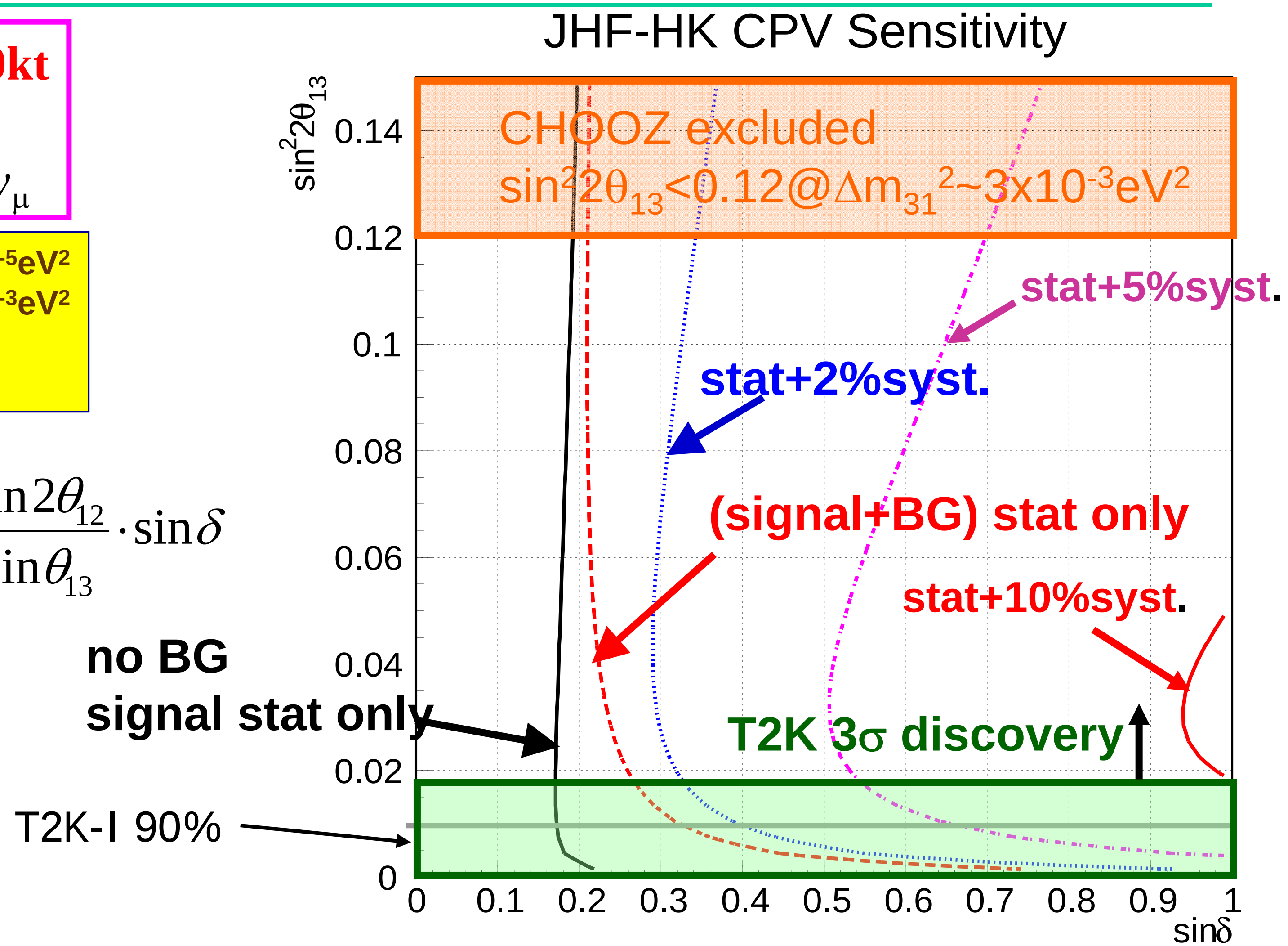


Future: 3σ Sensitivity for CPV in T2K-II

4MW, 540kt
2yr for ν_μ
6~7yr for $\bar{\nu}_\mu$

Δm_{21}^2=6.9x10^{-5}eV^2
Δm_{32}^2=2.8x10^{-3}eV^2
θ_{12}=0.594
θ_{23}=π/4

$$A_{CP} \approx \frac{\Delta m_{12}^2}{4E_\nu} \cdot \frac{\sin 2\theta_{12}}{\sin\theta_{13}} \cdot \sin\delta$$



3σ CP sensitivity : |δ|>20° for $\sin^2 2\theta_{13}$>0.01 with 2% syst.

Summary

- K2K
  - With 9.2×10^{19} POT, confirmed atmospheric neutrino oscillation at 4.2σ.

    (cf. 4.0σ published in PRL 94 (2005) 81802)
  - Observed spectrum distortion consistent with neutrino oscillation.
  - Many results are expected to come for neutrino interactions around 1 GeV region.
- T2K
  - Construction of T2K-I on schedule.
  - Seriously considering possibilities to double the beam power from the current baseline power (670 kW, 40 GeV).