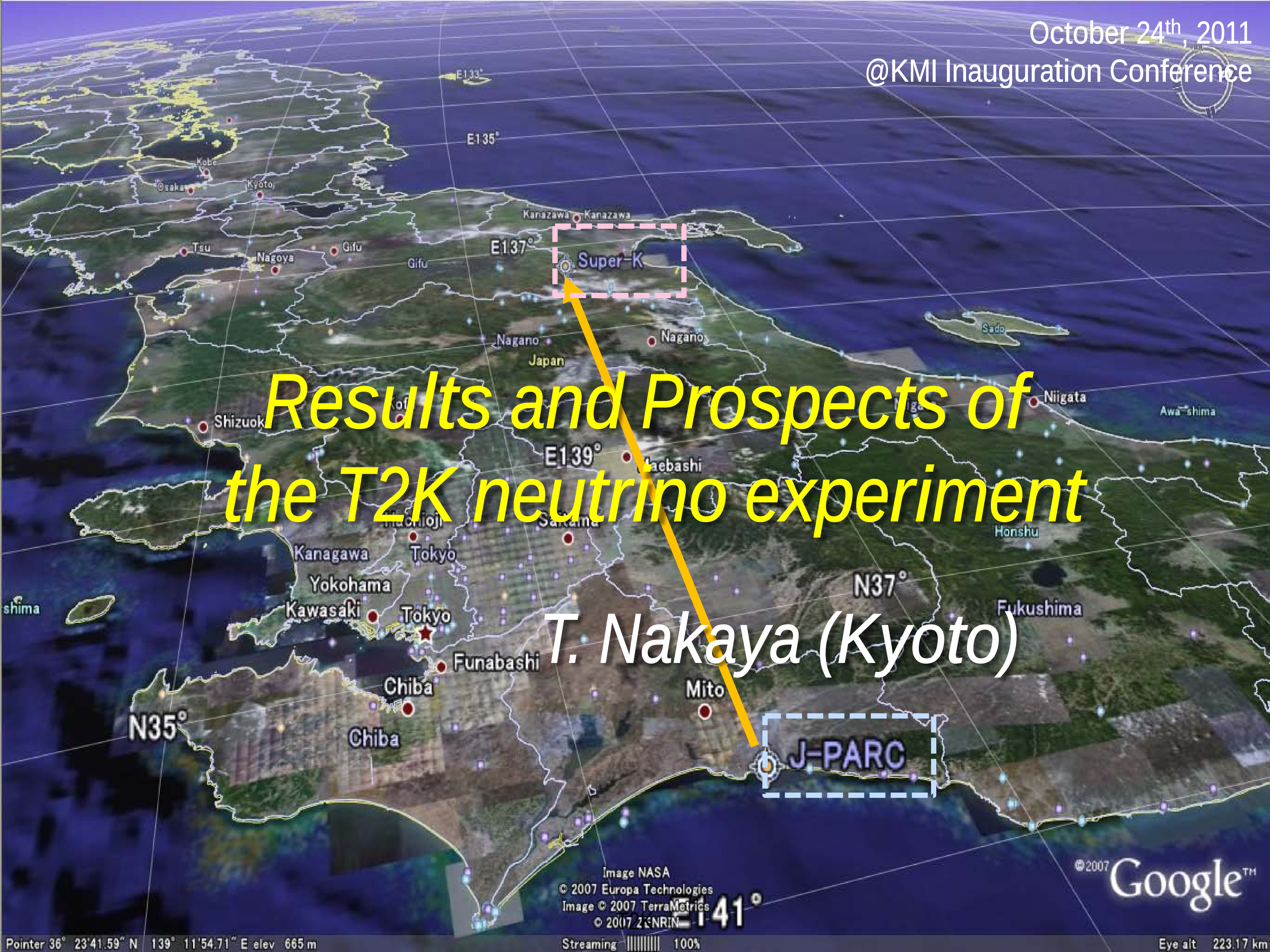
October 24th, 2011
@KMI Inauguration Conference

Results and Prospects of the T2K neutrino experiment

T. Nakaya (Kyoto)



Selected for a Viewpoint in *Physics*

PRL **107,** 041801 (2011) PHYSICAL REVIEW LETTERS week ending 22 JULY 2011

Indication of Electron Neutrino Appearance from an Accelerator-Produced Off-Axis Muon Neutrino Beam

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⋮ 400~500 authors

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The T2K experiment observes indications of $\nu_\mu \rightarrow \nu_e$ appearance in data accumulated with 1.43×10^{20} protons on target. Six events pass all selection criteria at the far detector. In a three-flavor neutrino oscillation scenario with $|\Delta m^2_{23}| = 2.4 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{23} = 1$ and $\sin^2 2\theta_{13} = 0$, the expected number of such events is 1.5 ± 0.3(syst). Under this hypothesis, the probability to observe six or more candidate events is 7×10^{-3}, equivalent to 2.5σ significance. At 90% C.L., the data are consistent with $0.03(0.04) < \sin^2 2\theta_{13} < 0.28(0.34)$ for $\delta_{CP} = 0$ and a normal (inverted) hierarchy.

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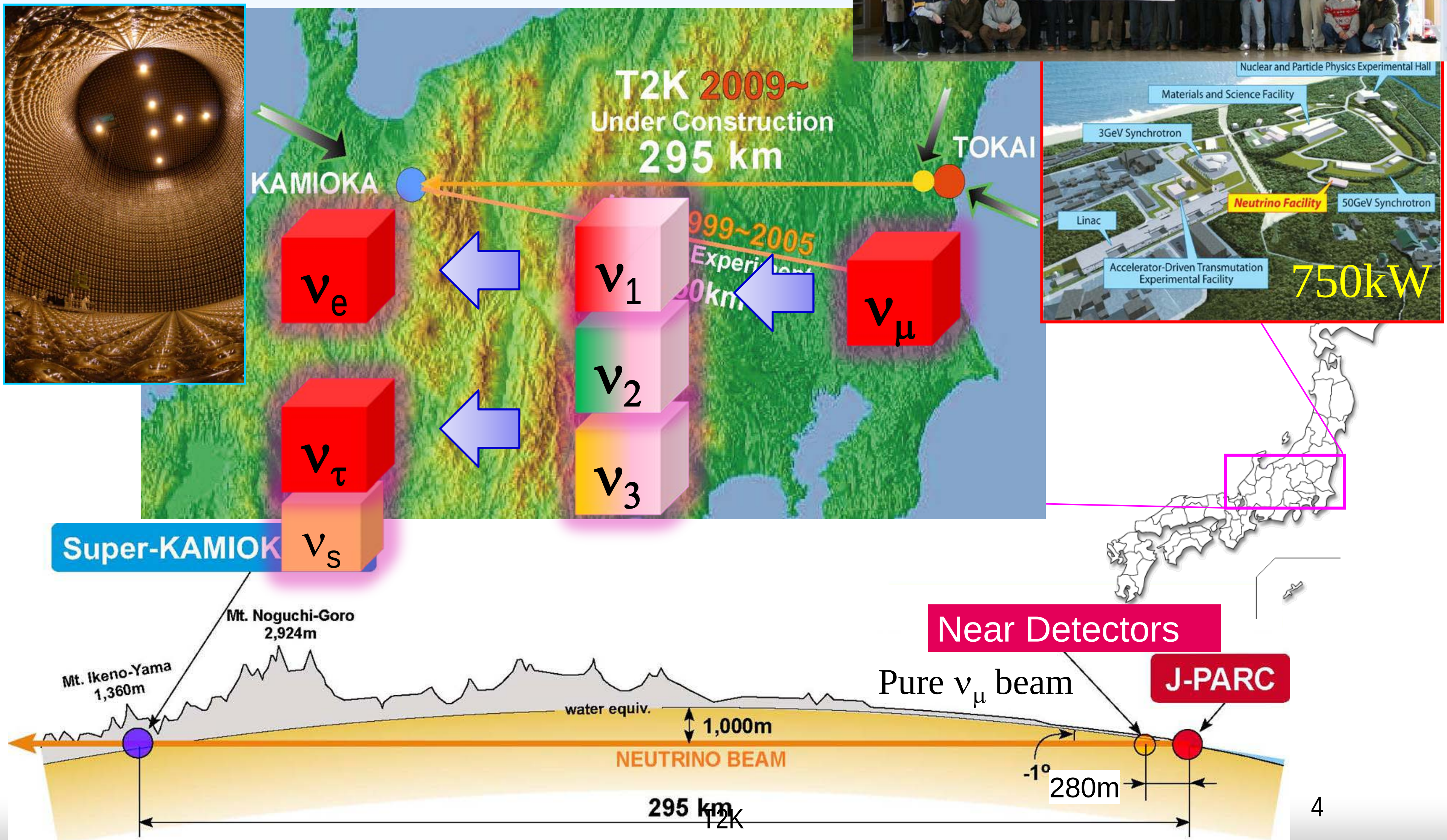
Citations in 4 month： 108

Outline

- Introduction to T2K
- Neutrinos
- Experimental Overview
- T2K results
  - νe appearance
  - ν_μ disappearance
- Future Prospect

1. Introduction to T2K



T2K Collaboration

Canada
U. Alberta
U. B. Columbia
U. Regina
U. Toronto
TRIUMF
U. Victoria
York U.

France
CEA Saclay
IPN Lyon
LLR E. Poly.
LPNHE Paris

Germany
U. Aachen

Italy
INFN, U. Bari
INFN, U. Napoli
INFN, U. Padova
INFN, U. Roma

Japan
ICRR Kamioka
ICRR RCCN
KEK
Kobe U.
Kyoto U.
Miyagi U. Edu.
Osaka City U.
U. Tokyo

Poland
A. Soltan, Warsaw
H.Niewodniczanski, Cracow
U. Silesia, Katowice
T. U. Warsaw
U. Warsaw
U. Wroclaw

Russia
INR

S Korea
Chonnam N. U.
U. Dongshin
Seoul N. U.

Spain
IFIC, Valencia
U. A. Barcelona

Switzerland
ETH Zurich
U. Bern
U. Geneva

UK
Imperial C. L.
Lancaster U.
Liverpool U.
Queen Mary U. L.
Oxford U.
Sheffield U.
STFC/RAL
STFC/Daresbury
Warwick U.

USA
Boston U.
B.N.L.
Colorado S. U.
U. Colorado
Duke U.
U. C. Irvine
Louisiana S. U.
U. Pittsburgh
U. Rochester
Stony Brook U.
U. Washington

International collaboration
(~500 members, 59 institutes, 12 countries）

2. Neutrino

- Neutrinos are one of the most abundant particles in our universe.
  - No. 1: Photons (light) [~400γ/cm^3]
  - No. 2: Neutrinos (~300ν/cm^3)

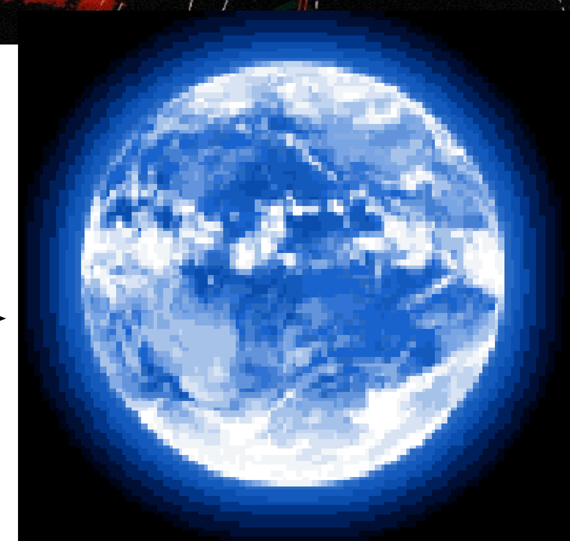
    although undetectable…
  - n_{Baryon}~0.000001/cm^3

***Not well-studied particles**: Mass?, composition?, #species?, speed?, magnetic moment?, etc..*

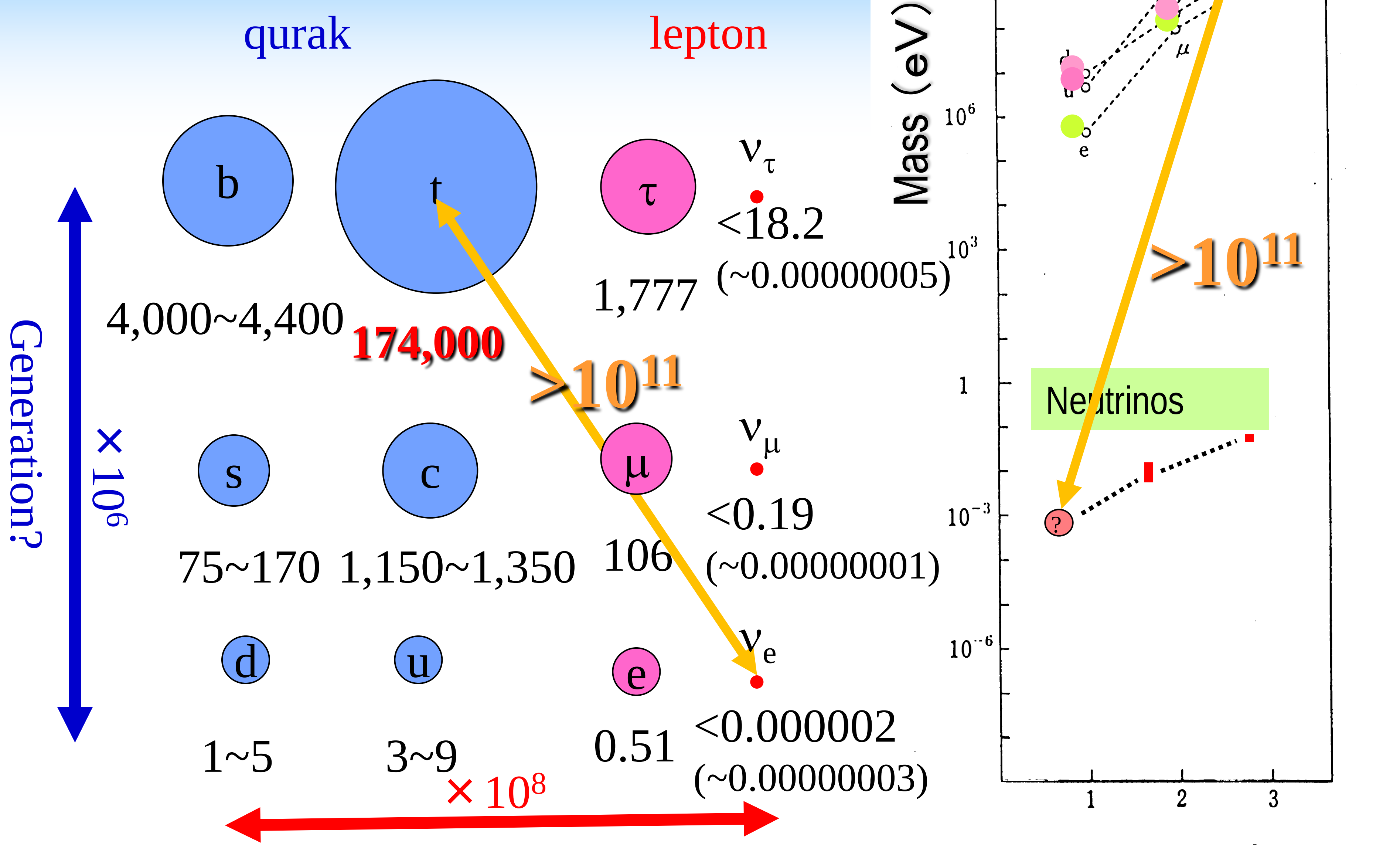
Neutrinos around us!

Nobel Prize in Physics, year 2002

60 billion νs per sec•cm^2



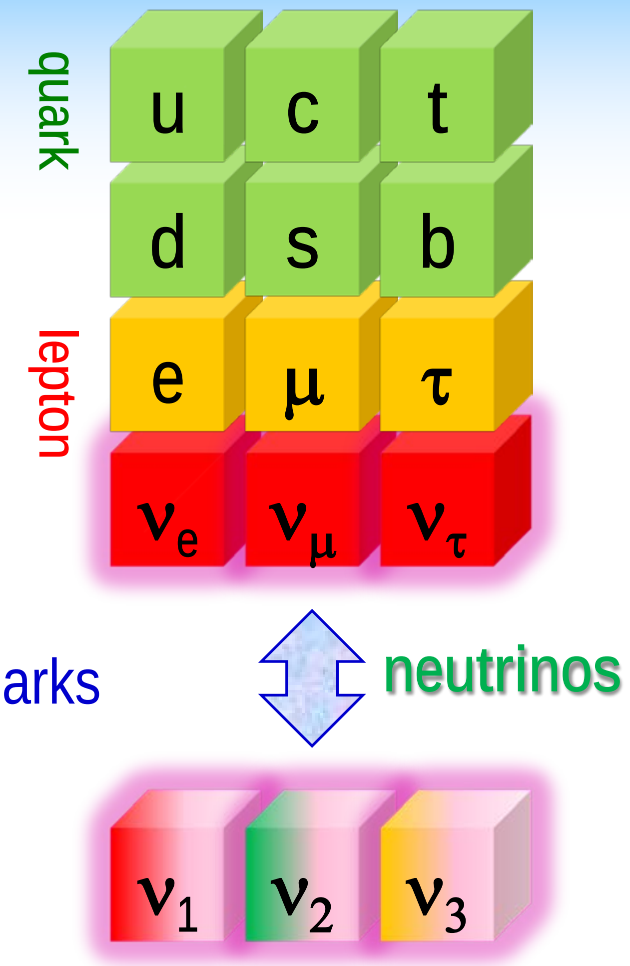
Mass(MeV) :



Neutrino is special?

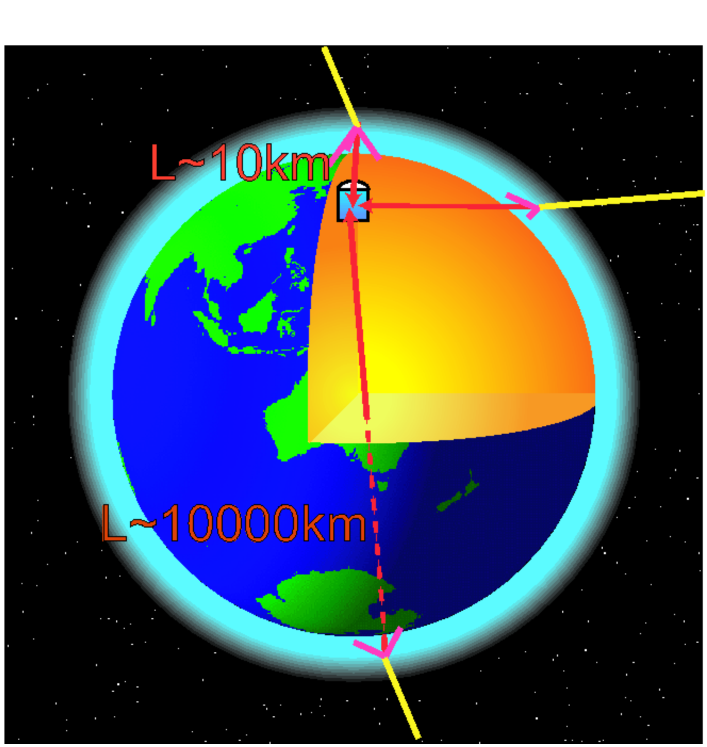
Neutrinos

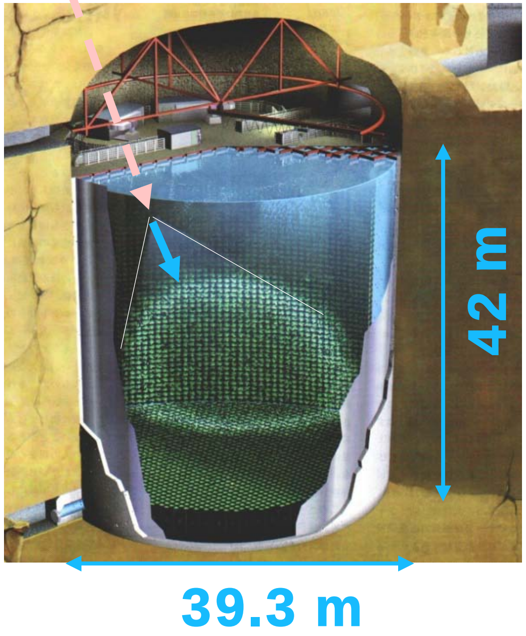
- Only have a week interaction
  - Small mass
    - Origin in physics beyond the standard model?
  - Mixing
    - 3 neutrinos are mixed
    - Different mixing patterns from that of quarks
      - What symmetry exists?
    - No experimental information on the CP symmetry

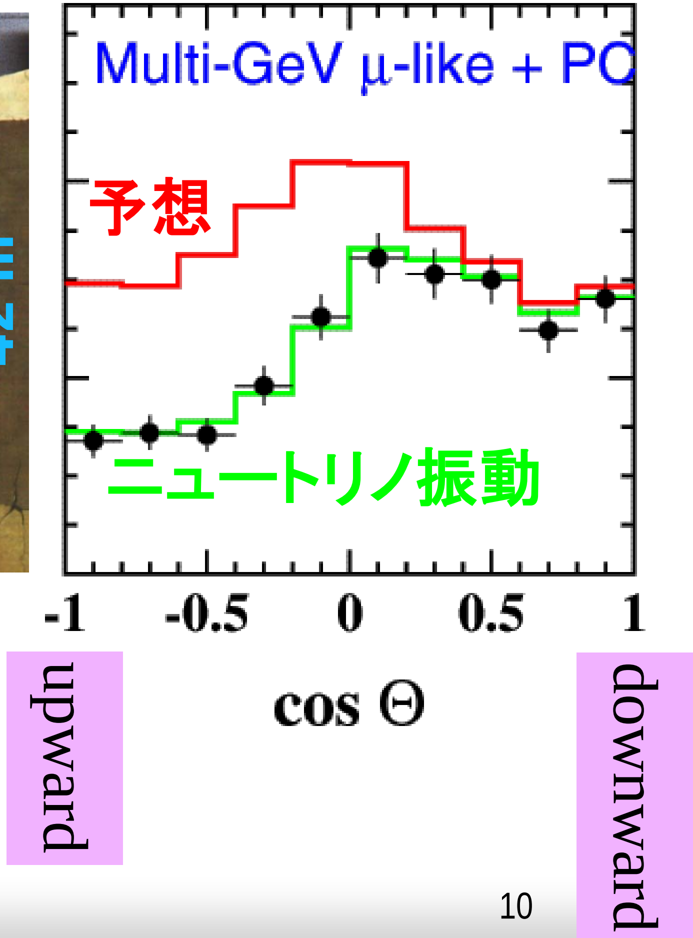


Much exciting to study neutrinos after the discovery of neutrino oscillation in 1998

Discovery of neutrino oscillation(1998)
Evidence of neutrino mass







Mixing Matrix

Nobel Prize in Physics, year 2008

Kobayashi-Maskaw matrix

weak state

a) The weak neutrinos must be re-defined by a relation

$$\left.\begin{aligned}\nu_e &= \nu_1 \cos\delta - \nu_2 \sin\delta,\\ \nu_\mu &= \nu_1 \sin\delta + \nu_2 \cos\delta.\end{aligned}\right\} \qquad (2\cdot18)$$

The leptonic weak current (2·9) turns out to be of the same form with (2·1). In the present case, however, weak neutrinos are *not stable* due to the occurrence of a virtual transmutation $\nu_e \rightleftarrows \nu_\mu$ induced by the interaction (2·10). If the mass difference between ν_2 and ν_1, i.e. $|m_{\nu_2} - m_{\nu_1}| = m_{\nu_2}{}^{*)}$ is assumed to be a few Mev, the transmutation time $T(\nu_e \rightleftarrows \nu_\mu)$ becomes $\sim 10^{-18}$ sec for fast neutrinos with a momentum of $\sim$Bev/c. Therefore, a chain of reactions such as[10)]

$$\pi^+ \to \mu^+ + \nu_\mu, \qquad (2\cdot19a)$$

$$\nu_\mu + Z\,(\text{nucleus}) \to Z' + (\mu^- \text{ and/or } e^-) \qquad (2\cdot19b)$$

is useful to check the two-neutrino hypothesis only when $|m_{\nu_2} - m_{\nu_1}| \lesssim 10^{-6}$ Mev

Particles

SAKATA

state

$$\begin{pmatrix} \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} V_{\mu 1} & V_{\mu 2} & V_{\mu 3} \\ V_{\tau 1} & V_{\tau 2} & V_{\tau 3} \end{pmatrix} \begin{pmatrix} \nu_2 \\ \nu_3 \end{pmatrix}$$

Mass state

T2K

Status of Neutrino Oscillation

??? LSND anomaly ???

Atmospheric neutrinos

ν_μ deficit (ν_τ appearance)

Δm_{23} region

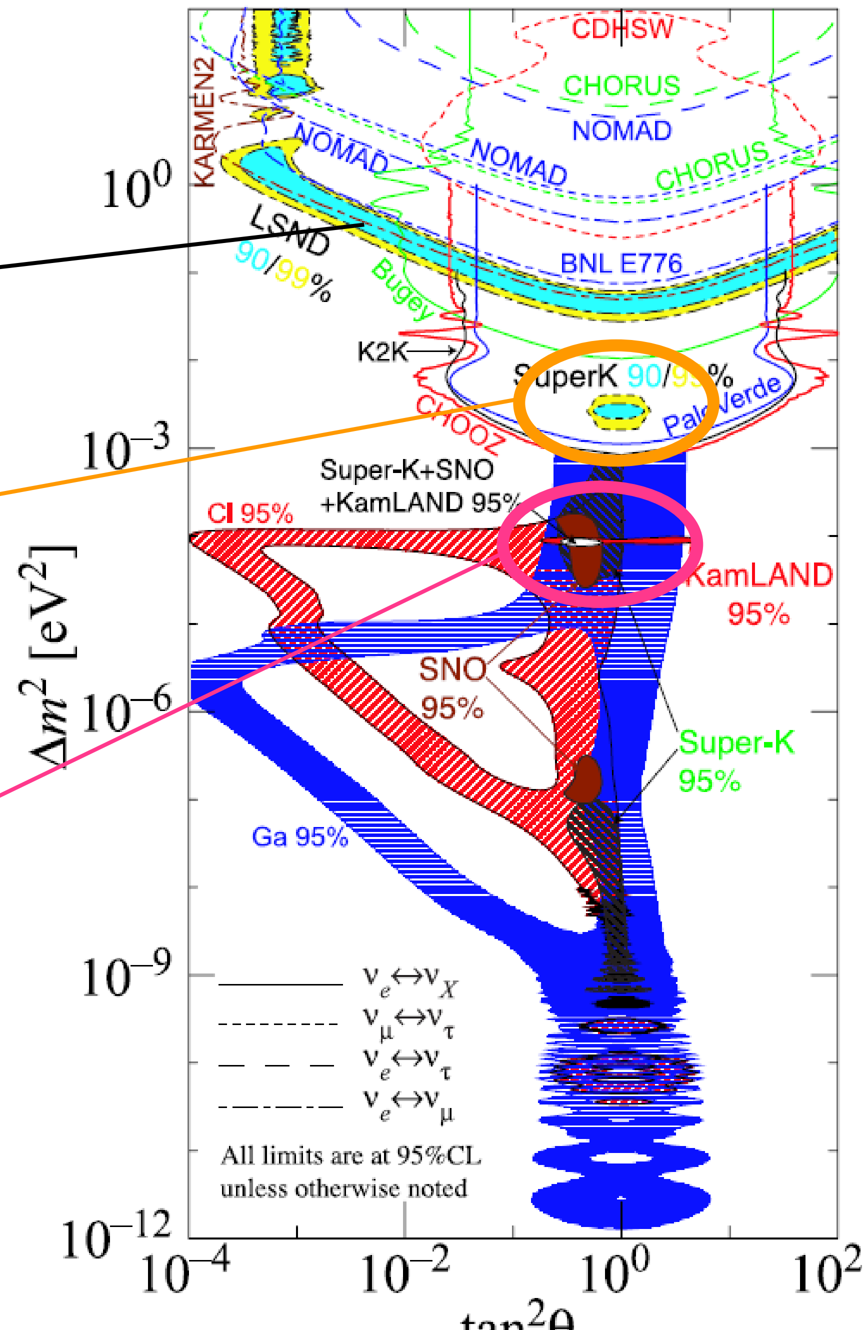
- $\Delta m_{23} \sim 2.5\times10^{-3}eV^2$
- $\sin^2 2\theta_{23} \sim 1.0$

solar neutrinos

ν_e deficit (NO NC deficit)

Δm_{12} region

- $\Delta m_{12} \sim 7.9\times10^{-5}eV^2$
- $\sin^2 2\theta_{12} \sim 0.82$



T2K

Neutrino Oscillation parameters with the MSN Matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U_{PMNS} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

$$s_{ij} = \sin\theta_{ij},\ c_{ij} = \cos\theta_{ij}$$

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

Ignore majorana phase

- Neutrino oscillation parameters

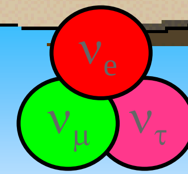
  3 Mixing Angles (θ_{12}, θ_{23}, θ_{13}), CP violating phase (δ)

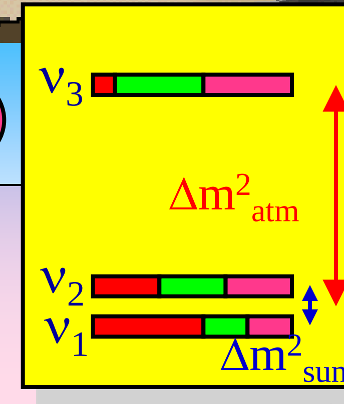
  mass square difference (Δm^2_{12}, Δm^2_{23})

$\theta_{12} = 34^o \pm 3^o$ $\Delta m^2_{12} \sim 8 \times 10^{-5}$ (eV^2) Solar ν, Reactor ν	$\theta_{23} = 45^o \pm 5^o$ $\lvert\Delta m^2_{23}\rvert \sim 2.5 \times 10^{-3}$ (eV^2) Atmospheric ν, accelerator ν	$\theta_{13} < 11^o$ ($\sin^2 2\theta_{13} < 0.15$) Accelerator ν, Reactor ν

A hint of θ_{13} from T2K (θ_{13} ~10 degrees)

Measured quantities in T2K





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

- θ_{23} : ν_μ disappearance

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

common

- θ_{13}: ν_e appearance

$$P_{\nu\mu\to\nu e} \approx \underbrace{\sin^2\theta_{23}}_{\sim 0.5} \cdot \sin^2 2\theta_{13} \cdot \sin^2\left(1.27\Delta m^2_{23} L / E_\nu\right)$$

- δ : CP violation (T2K-beyond)

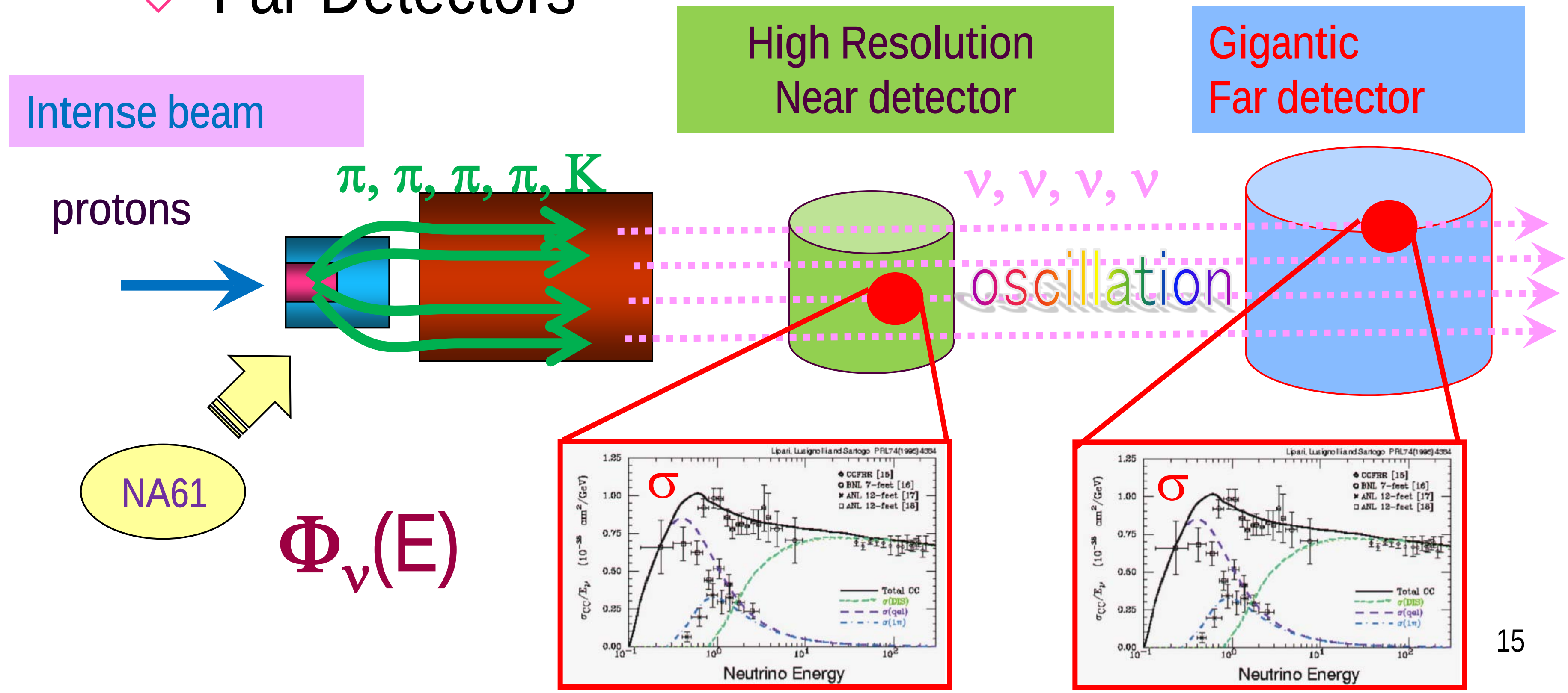
$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\overline{\nu}_\mu \to \overline{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\overline{\nu}_\mu \to \overline{\nu}_e)} \cong \cdot \sin\delta$$

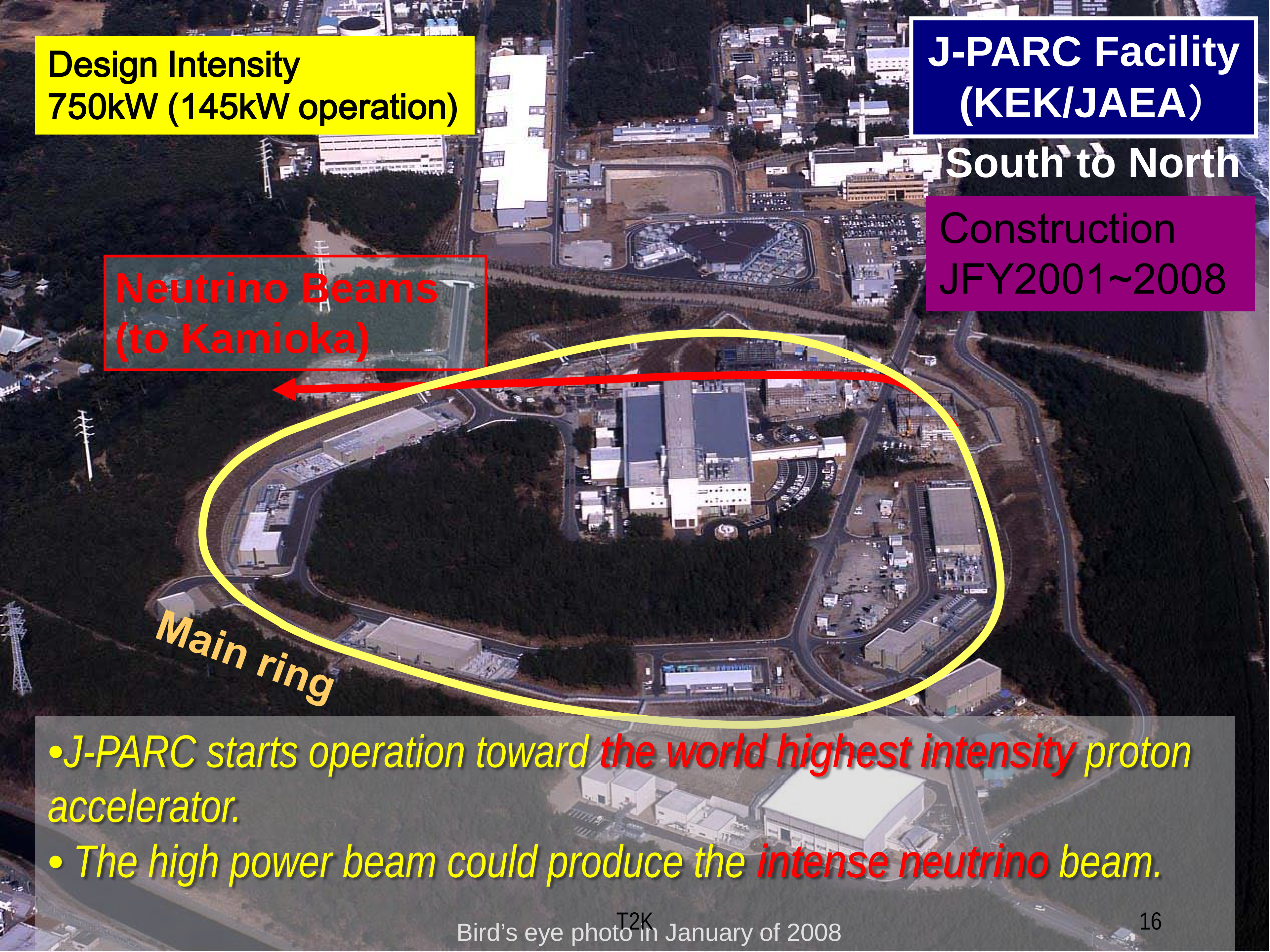
~0.18 ($\sin^2 2\theta_{13}$=0.1)

~0.58 ($\sin^2 2\theta_{13}$=0.01)

2. Experimental Overview

- Accelerator/Neutrino Beams
- Near Detectors
- Far Detectors

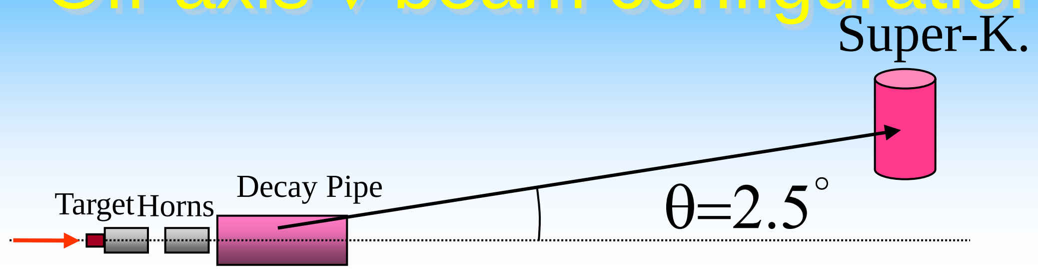




- *J-PARC starts operation toward **the world highest intensity** proton accelerator.*
- *The high power beam could produce the **intense neutrino** beam.*

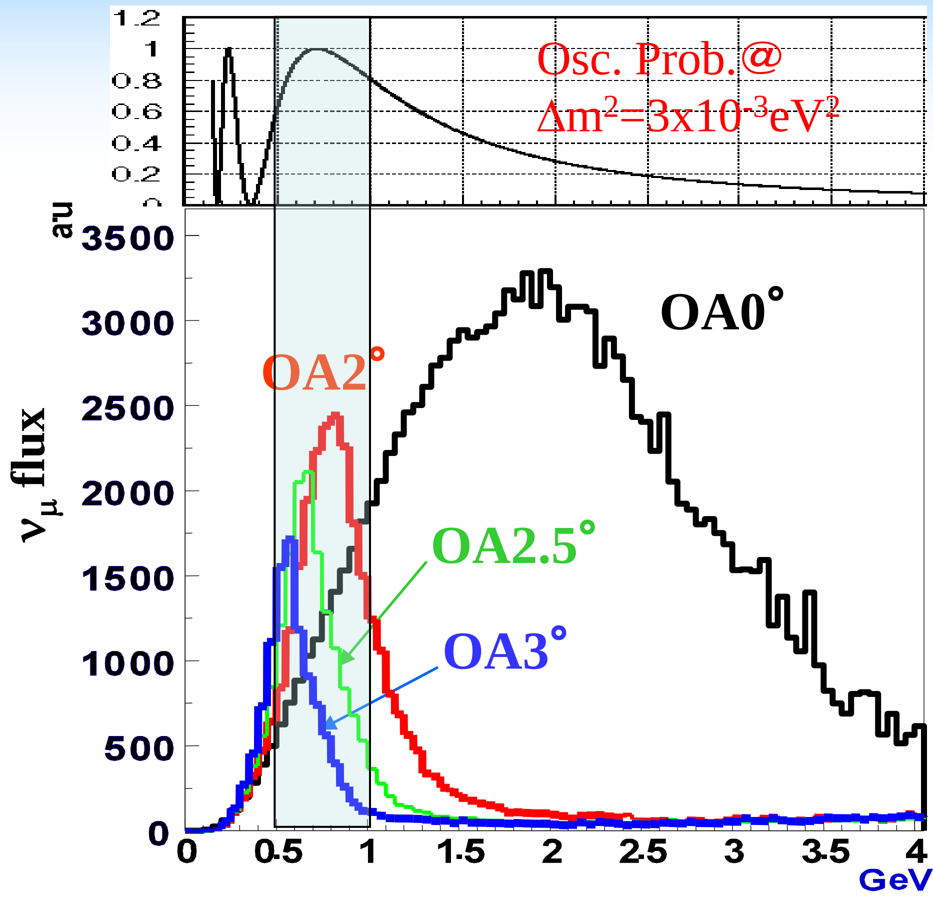
Bird's eye photo in January of 2008

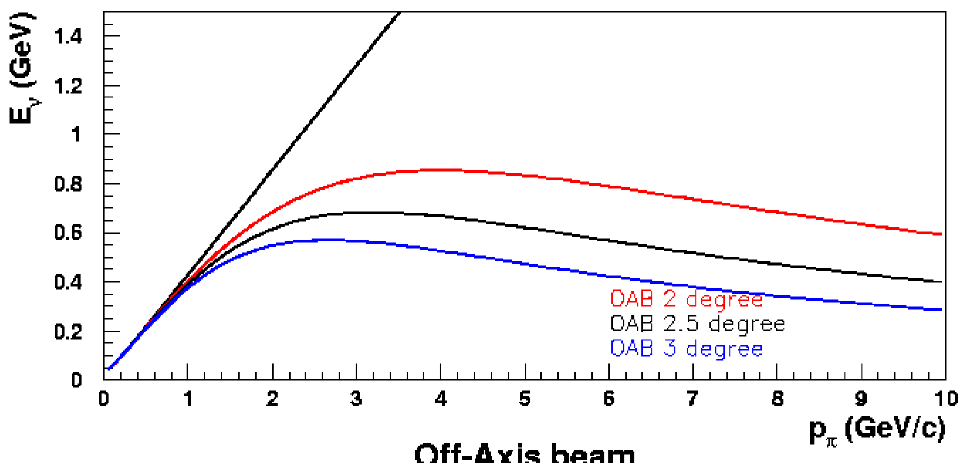
Off-axis ν beam configuration



- The ν beam energy is tuned at the oscillation maximum.
  - Higher signal yield.
  - Less background from high energy neutrinos.

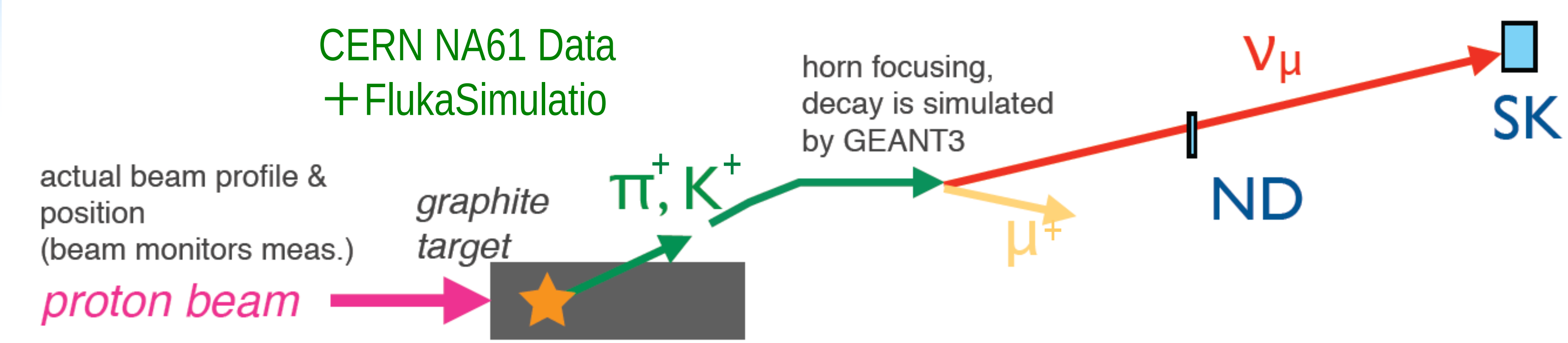
◆ **Quasi Monochromatic Beam**





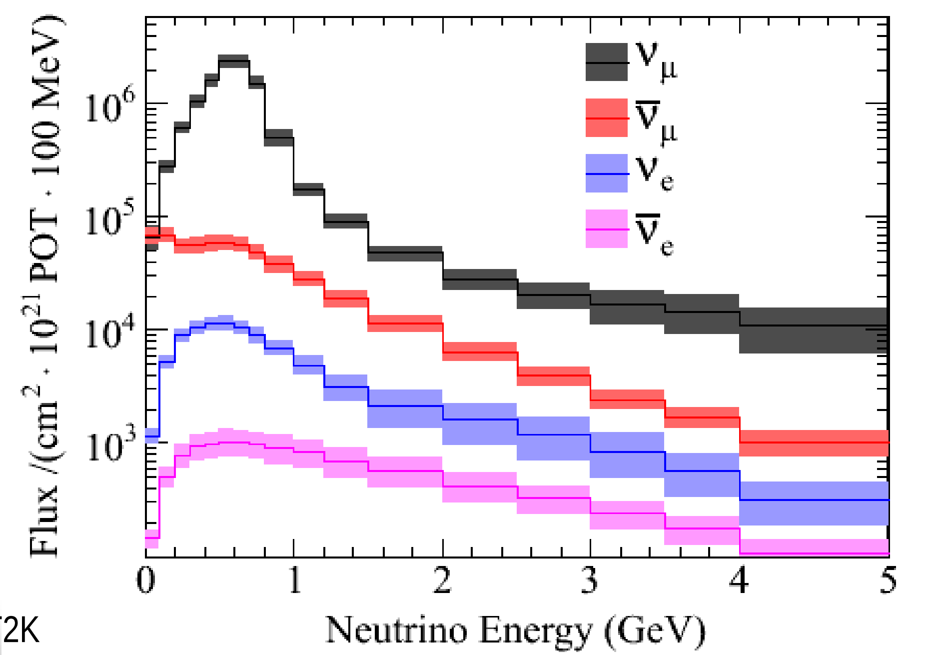
Intense and high-quality neutrino beam

Neutrino Beam Flux

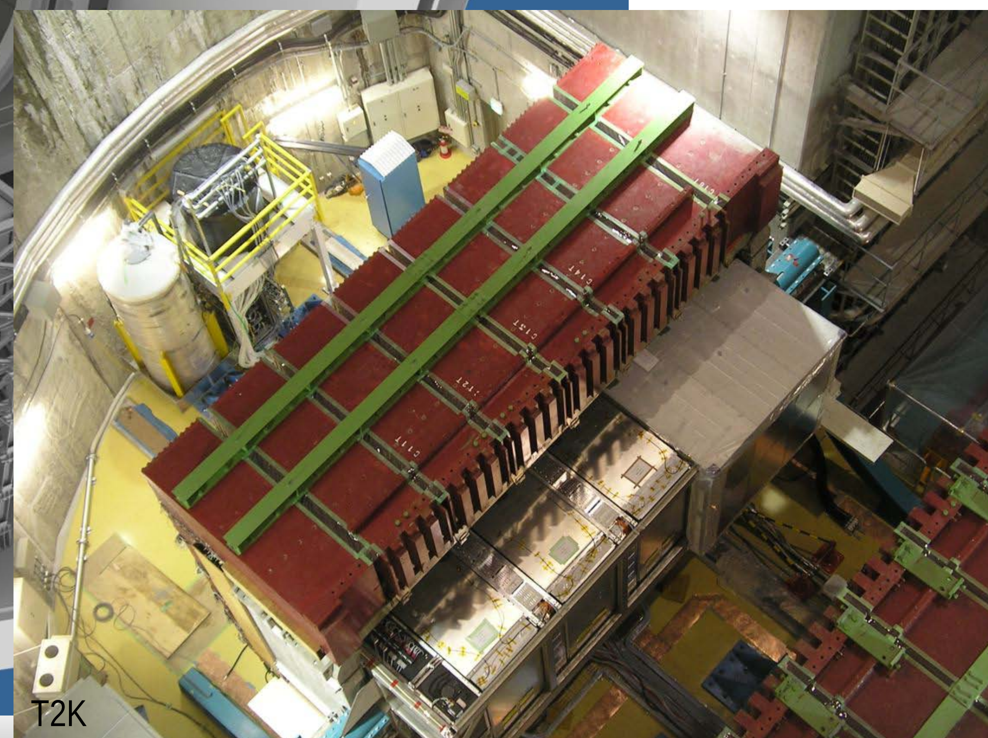


- Neutrino Beam Flux is precisely estimated based on
  - Real pion production data measured by CERN NA61
  - With the uncertainties based on the measurement.

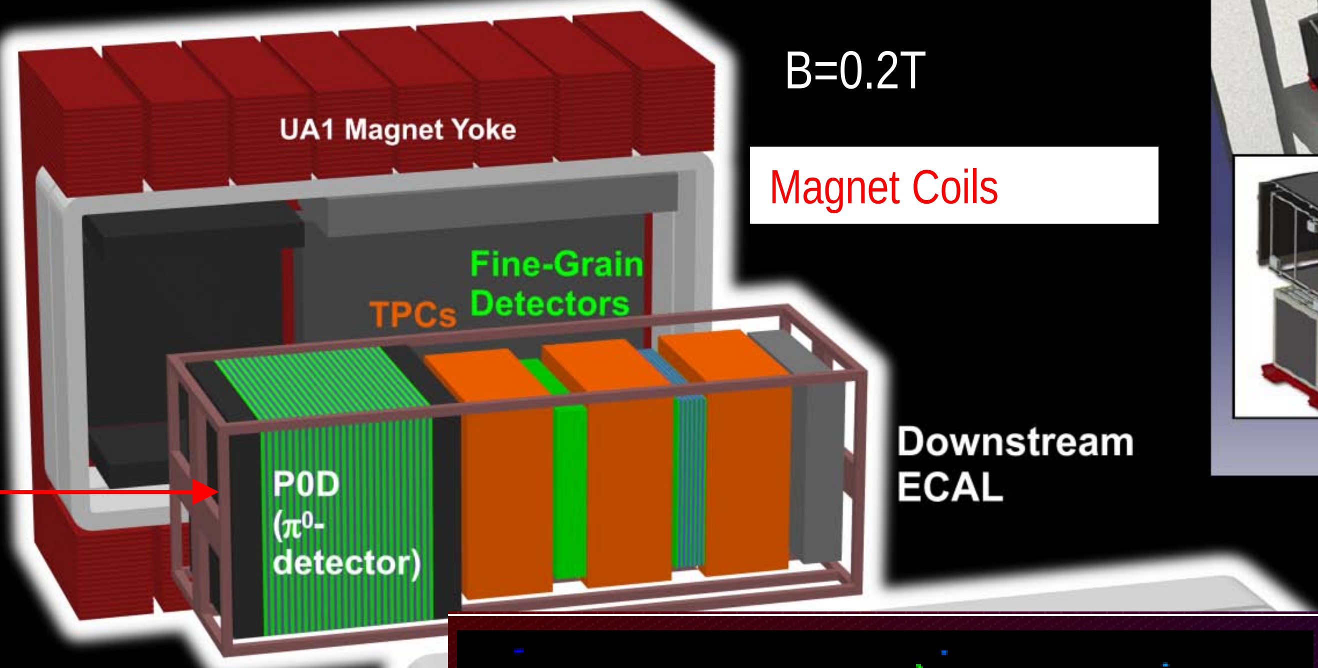
Estimated Neutrino Flux at Super-K



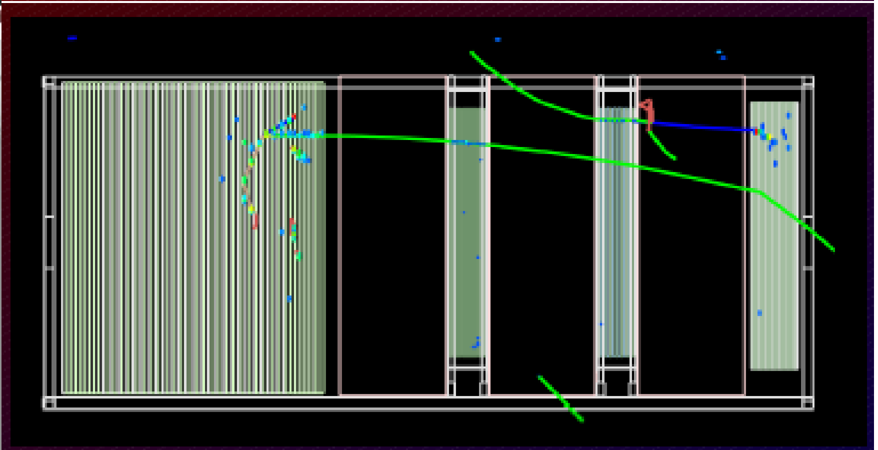
ND280
(Near Neutrino Detectors)



ND280 Off-axis

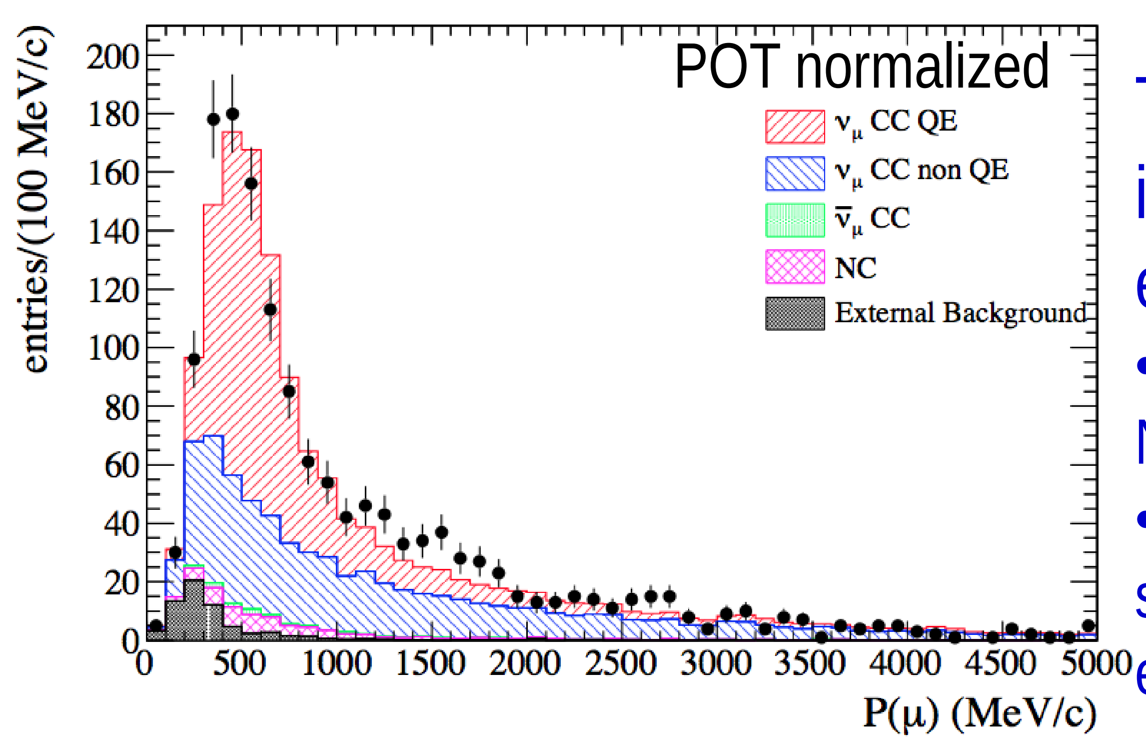


- Volume:
  - $3.5\times3.5\times7.0m^3$
- P0D: π^0 Detector
- FGD+TPC: Charged Particle tracking
- EM calorimeter
- Side-Muon-Range Detector



A CC1π interaction in the P0D, with full-bunch background

ν_μ CC measurement at ND280



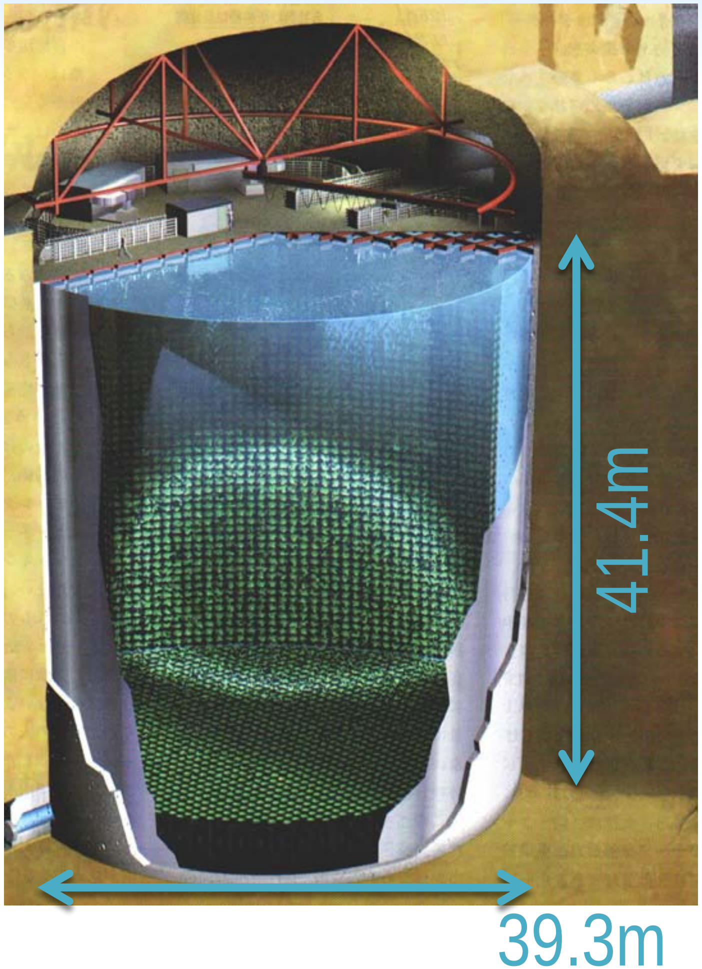
The ND280 measurement is consistent with the estimation based on

- Beam simulation with CERN NA61 data
- Neutrino Interaction simulation with the world existing data.

$$R_{ND}^{\mu,\,Data} = 1529 \;\; \text{events} \;/\; 2.9 \times 10^{19} \;\; \text{p.o.t.}$$

$$\frac{R_{ND}^{\mu,\,Data}}{R_{ND}^{\mu,\,MC}} = \underline{1.036} \pm 0.028(\text{stat.})^{+0.044}_{-0.037}(\text{det. syst.}) \pm 0.038(\text{phys. syst.})$$

Super-Kamiokande



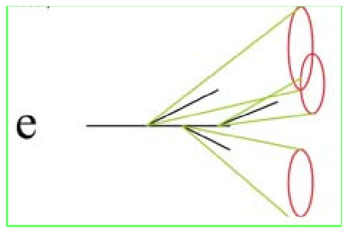
©Scientific American

- 1km underground
- Water Cherenkov detector with 50kton mass (22.5 kton Fiducial volume)
  - Inner tank:11,129 20inch PMT
  - Outer tank:1,885本の8inch PMT
- Dead-time-less DAQ (2008～)
- GPS timing information is recorded real-time at every accelerator spill
  - Record all events with the timing of ±500μsec from the neutrino arrival time as a T2K event.

Electron-like & muon-like event at SK

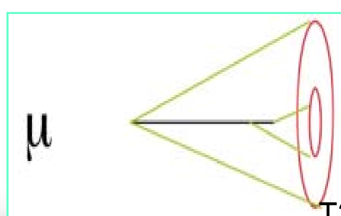
ν_eCC simulation

e-like

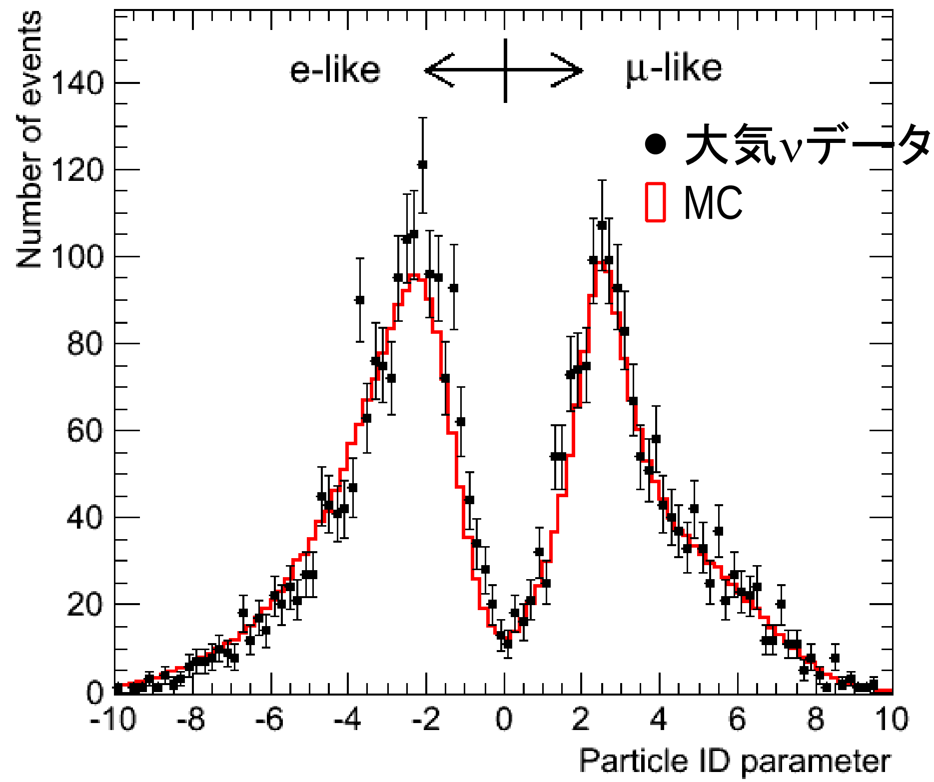


ν_μCC simulation

μ-like



Particle Identification (PID) by the ring pattern and opening angle



Mis-ID probability is ~1%

T2K Beam data

#Protons on Target (POT)

protons/spill

Run 1 (2010 Jan – 2010 Jul)

- 50kW stable beam operation

Run 2 (2010 Nov – 2011 Mar)

- reached 145kW beam operation

All data for this analysis is1.43 x 10^{20} POT

（2% of the proposal）

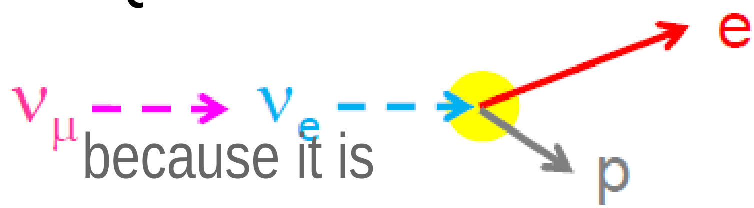
POT = The number of protons on target

T2K results

ν_e appearance

Signal and Background

- **Signal: ν_e oscillation from ν_μ**
  - A main interaction is Charged-Current Quasi-Elastic (CCQE) : $\nu_e + n \rightarrow e^- + p$

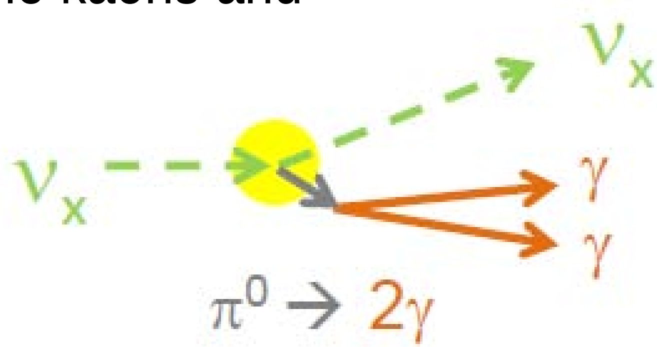


  - The proton is often not observed because it is below the Cherenkov threshold

- **Background**

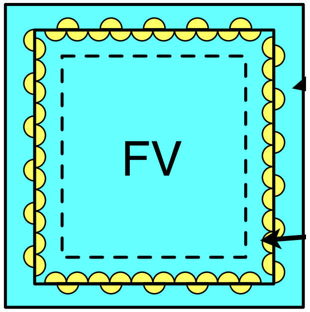
  (1) ν_e in the beam mainly from the decay of the kaons and muons

  (2) Neutral-Current π^0 production ($\pi^0 \rightarrow \gamma\gamma$)
  - ❖ 2γ rings are overlapped to one
  - ❖ A γ energy is too low to be detected.



SK event selection

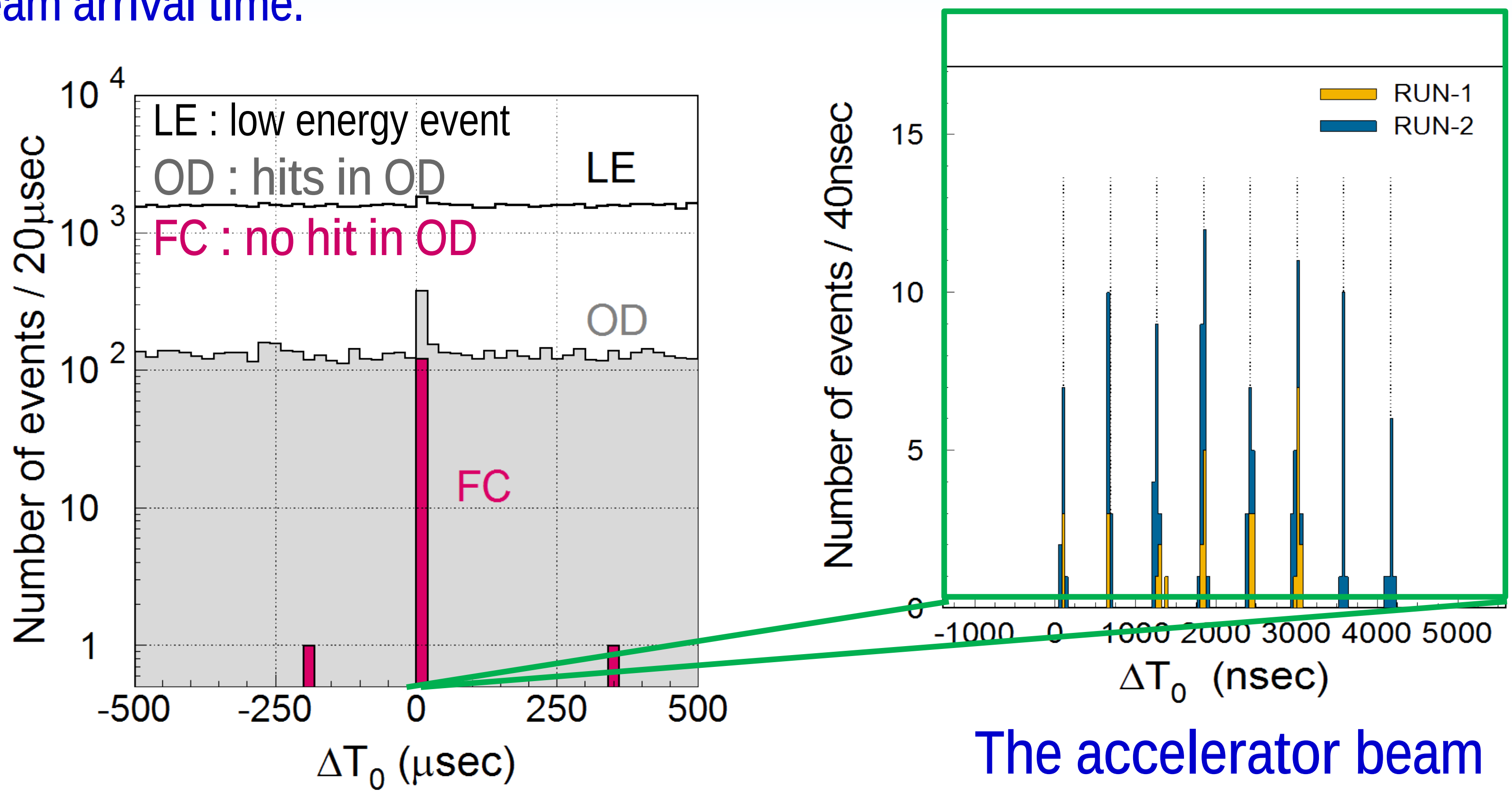
1. T2KBeam timing
2. Fully-Contained and the vertex is in the Fiducioal Volume (FCFV)
3. 1 Cherenkov Ring
4. Electron-like
5. Visible energy (E_{vis}) $\geqq$ 100MeV
6. No additional electron signal caused by the muon decay.



SK events in T2K beam timing

Event time distributions relative to the beam arrival time.

Zoom-up

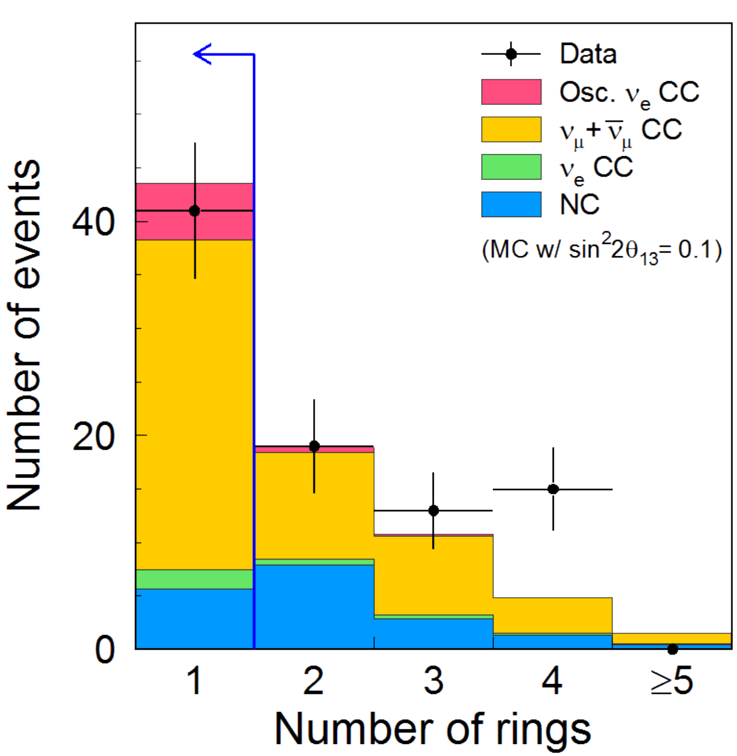


The accelerator beam structure is clearly seen.
→ The beam neutrinos

Two out-of-time events are background consistent with atmospheric neutrinos.

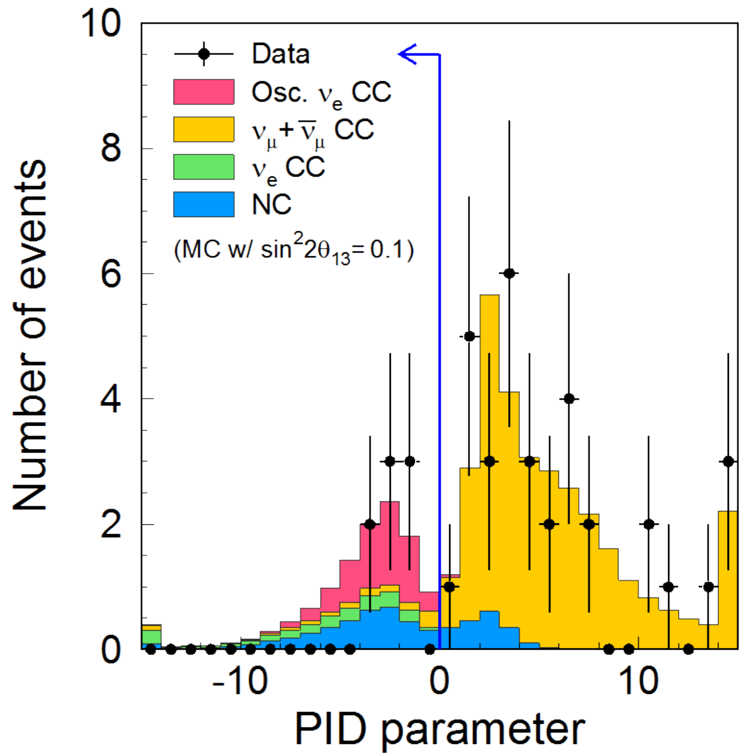
Event Selection

Cherenkov rings (1 ring)



41 events

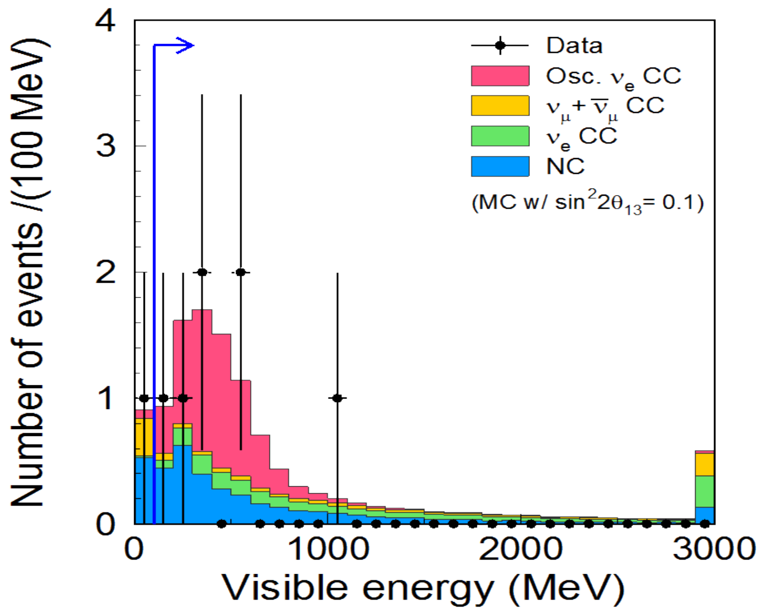
PID parameter (electron-like)



8 events

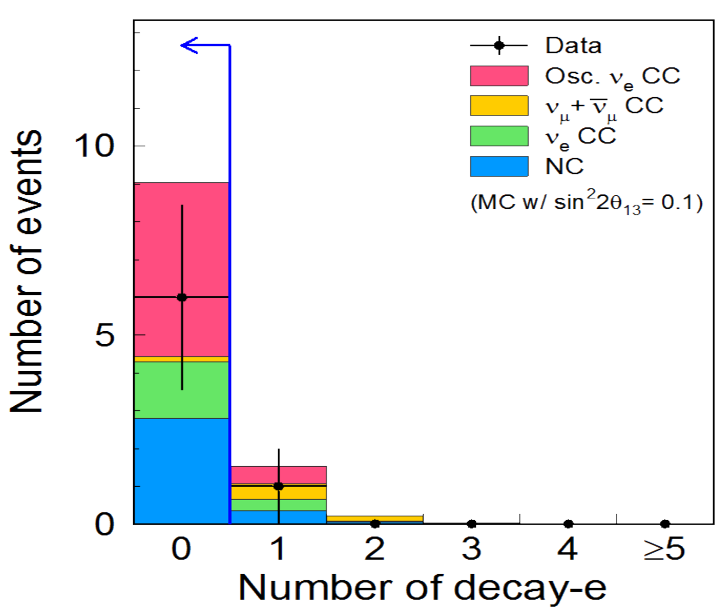
Event Selection (continued)

Visible energy (>100MeV)



7 events

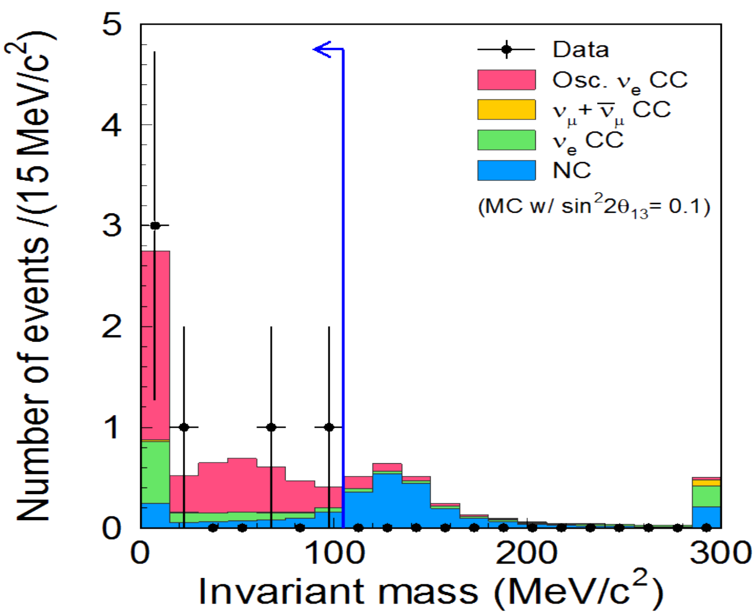
Decay electron (0)



6 events

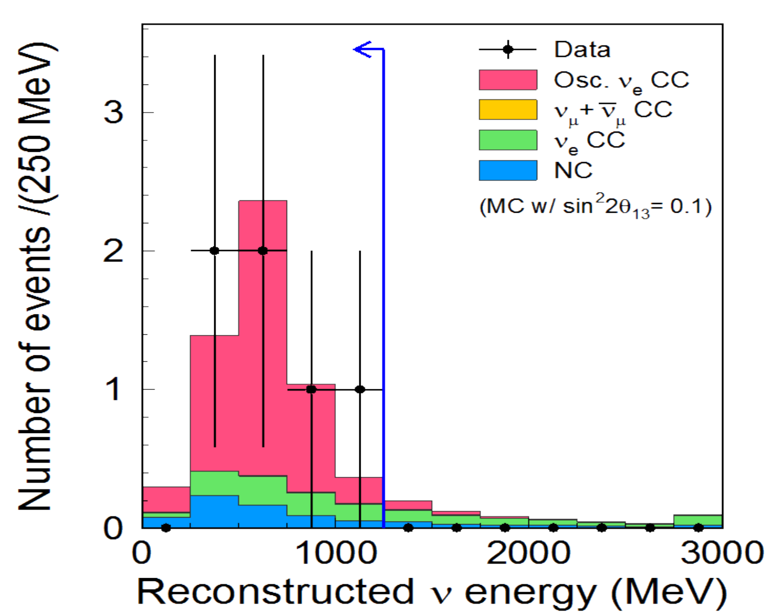
More selections

Invariant mass of assumed two rings (<105MeV/c^2)



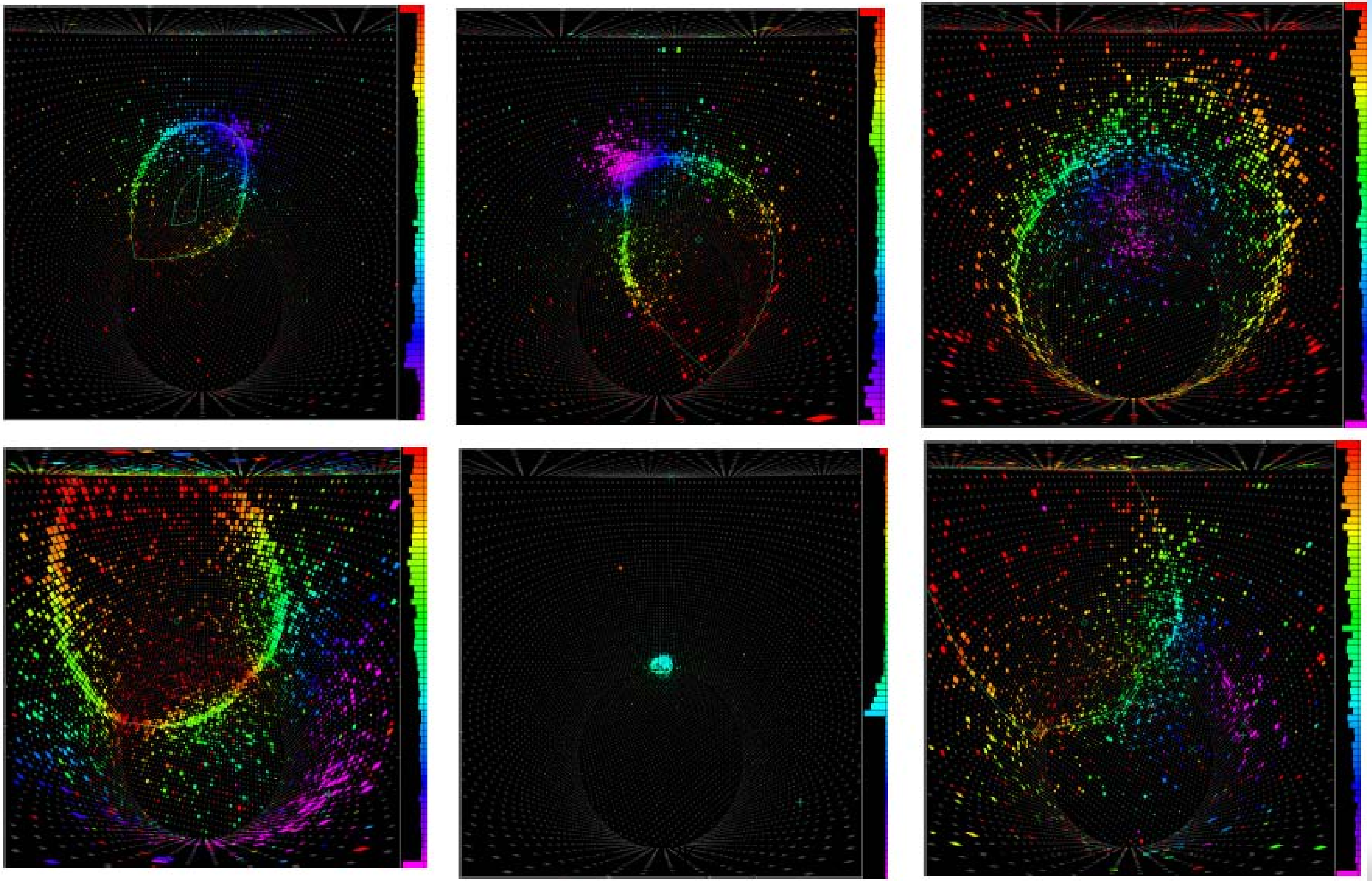
6 events

Reconstructed E_ν < 1250MeV



6 events observed!

Electron Neutrino candidates



Prediction of the SK e-like events

- Number of SK events by MC
  - Beam simulation
  - Neutrino interaction simulation
  - Detector simulation
  - Neutrino oscillation

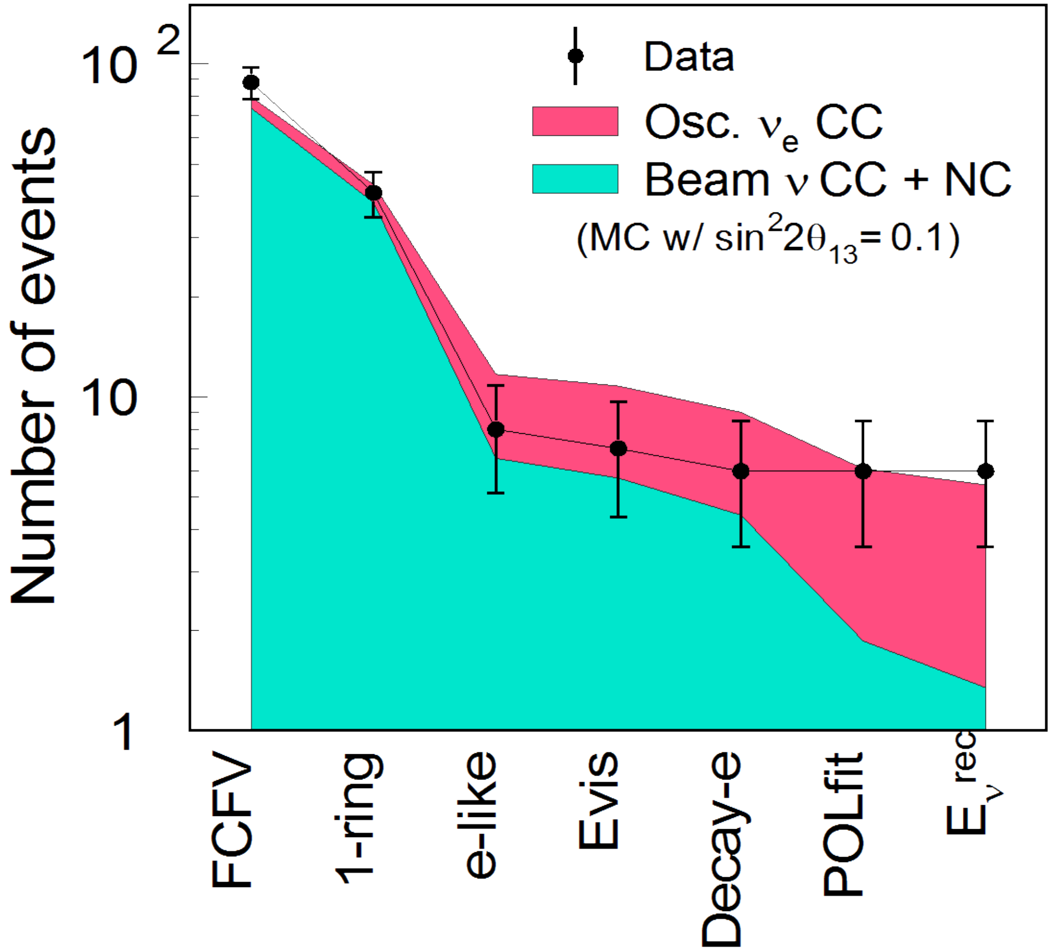
$\sin^2 2\theta_{12}=0.8704$
$\sin^2 2\theta_{23}=1.0$
$\sin^2 2\theta_{13}=0$ or 0.1
$\Delta m_{12}^2=7.6\times 10^{-5}eV^2$
$\Delta m_{23}^2=\pm 2.4\times 10^{-3}eV^2$

×

- Normalization by measured ND ν_μ rate

The absolute beam flux is normalized by the measurement of the Charged-Current ν_μ interactions in ND280.

Events at each stage ($\sin^2 2\theta_{13}=0.1$)



ν_e events at $\sin^2 2\theta_{13} = 0$ w/ systematic errors.

- The expected # of events with 1.43×10^{20} p.o.t. :

$$N_{SK}^{exp} = 1.5 \pm 0.3 \text{(syst.)}$$

for $\sin^2 2\theta_{13} = 0$

($\Delta m^2_{23}=2.4\times10^{-3}$ eV^2, $\sin^2 2\theta_{23}=1.0$)

Source	#events
Beam ν_μ CC	0.03
Beam ν_e CC	0.8
NC	0.6
Osc $\nu_\mu \rightarrow \nu_e$ (via solar term)	0.1
Total	1.5

error source	Systematic errors
ν flux	$\pm 8.5\%$
ν int. cross section	$\pm 14.0\%$
Near detector	$^{+5.6}_{-5.2}\%$
Far detector	$\pm 14.7\%$
Near det. statistics	$\pm 2.7\%$
Total	$^{+22.8}_{-22.7}\%$

ν flux: Uncertainties of the hadron production (mainly kaons) and the beam properties

ν int. cross section: Uncertainness of the neutrino interaction models and the hadron propagation in nucleus.

Far detector: Uncertainties of the SK detector performance (ring-counting, PID and invariant mass cut)

Electron Appearance Result

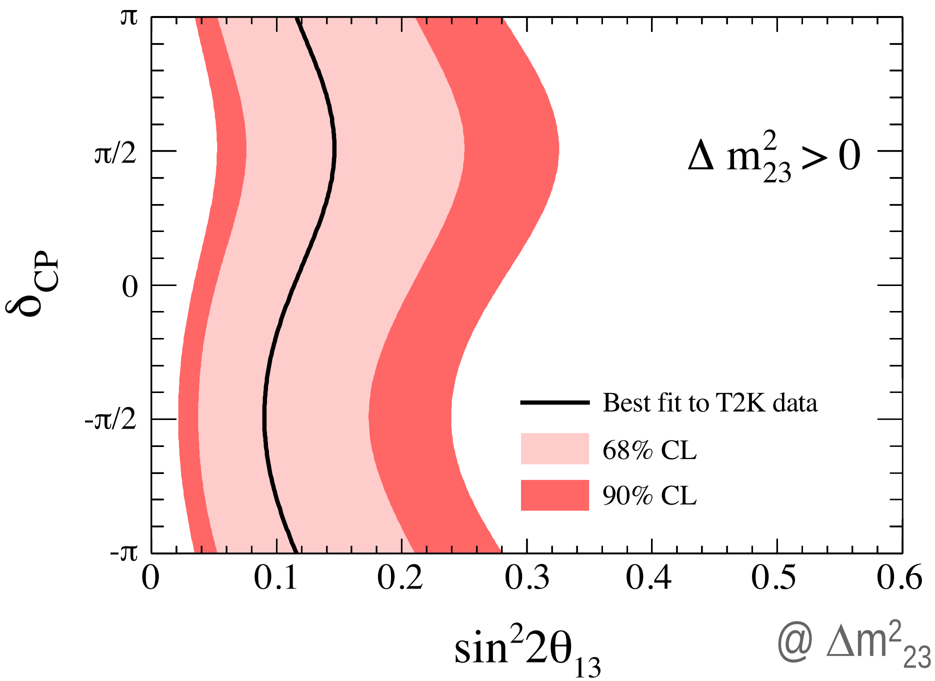
- #Observed: 6
  - #Expected at $\sin^2 2\theta_{13}=0$; 1.5 ± 0.3
- The probability is 0.7%（~2.5σ significance）when we observed 6 or more events with the expectation of 1.5±0.3

→ ***Indication of ν_e appearance ($\theta_{13}\neq 0$)***

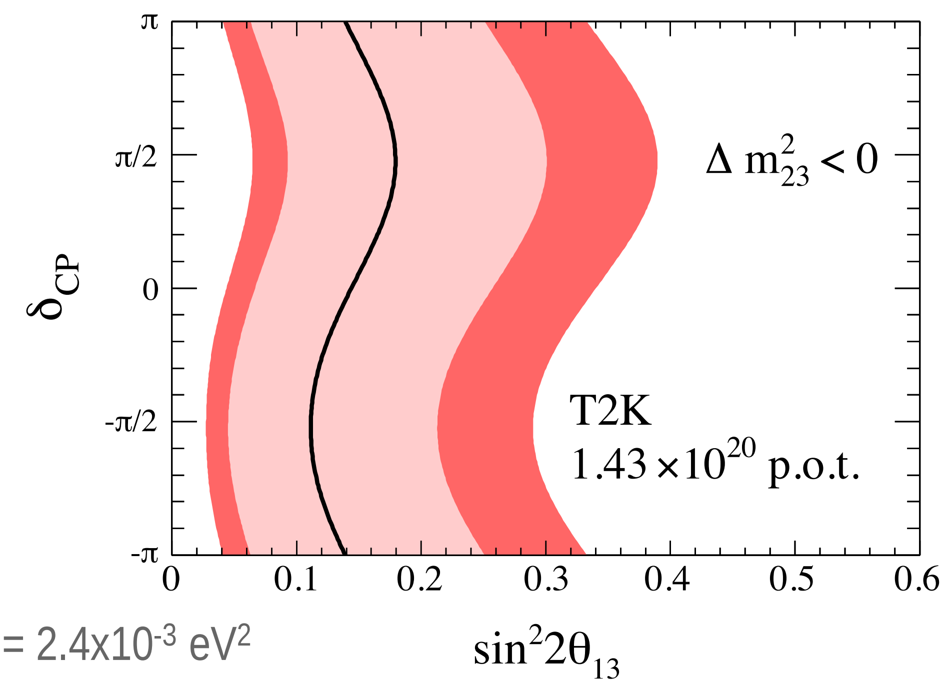
Allowed region of $\sin^2 2\theta_{13}$ versus δ

The allowed region was selected based on the three-generation mixing.

Normal Hierarchy



Inverted Hierarchy

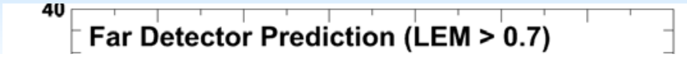


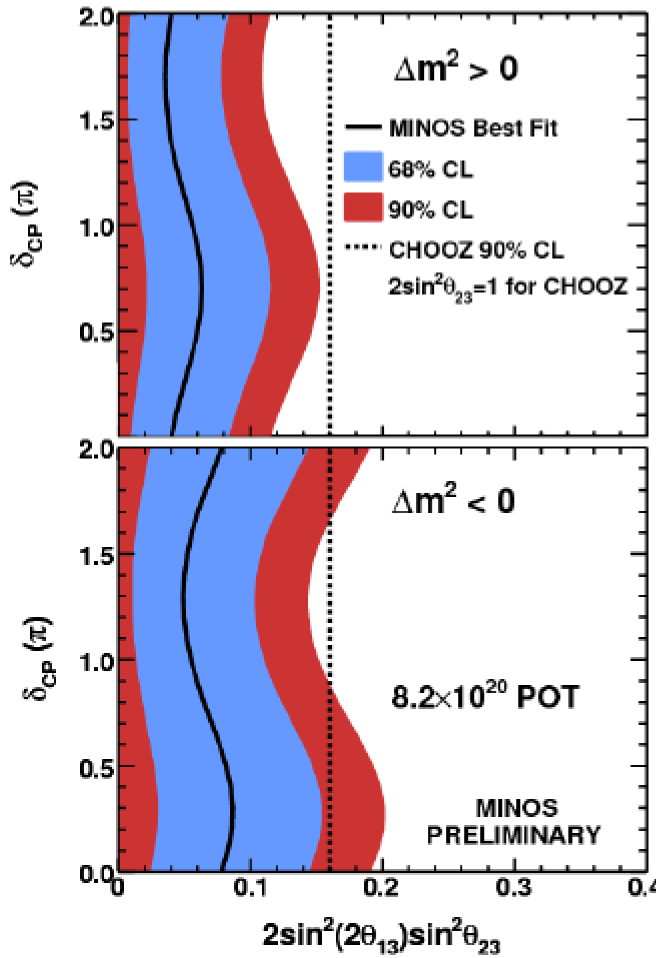
@ $\Delta m^2_{23} = 2.4 \times 10^{-3}$ eV^2

90%CL interval (assuming $\Delta m^2_{23} = 2.4 \times 10^{-3}$ eV^2 , $\delta_{CP} = 0$)

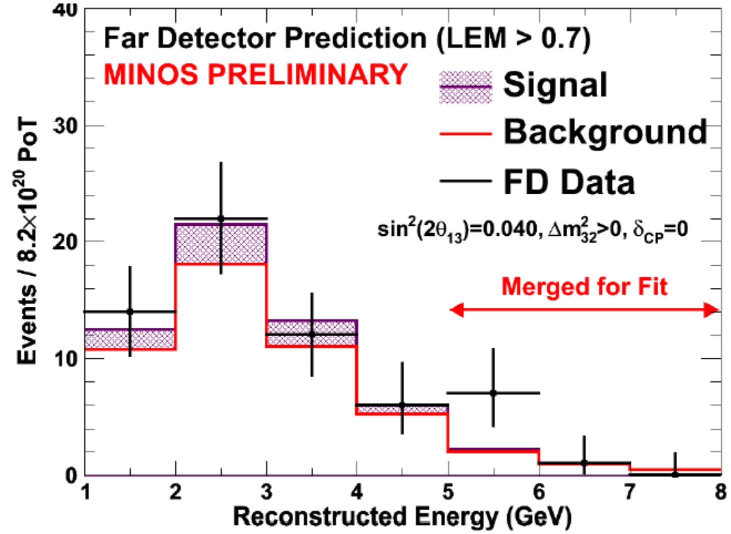
$0.03 < \sin^2 2\theta_{13} < 0.28$ $0.04 < \sin^2 2\theta_{13} < 0.34$

Reference
MINOS confirms the T2K result.





Assuming:
$\delta=0$, $\theta_{23} = \pi/4$
normal (inverted)



$$\sin^2(2\theta_{13}) < 0.12\,(0.19)$$

90% CL

$$\sin^2(2\theta_{13}) = 0.04\,(0.08)$$

Best Fit

We exclude $\sin^2 2\theta_{13}=0$ at 89% CL

- # ν_e observed： 62
- Estimated events at（$\theta_{13}=0$）： 49.5±7.0±2.8

Consistent with T2K

T2K results
ν_μ disappearance

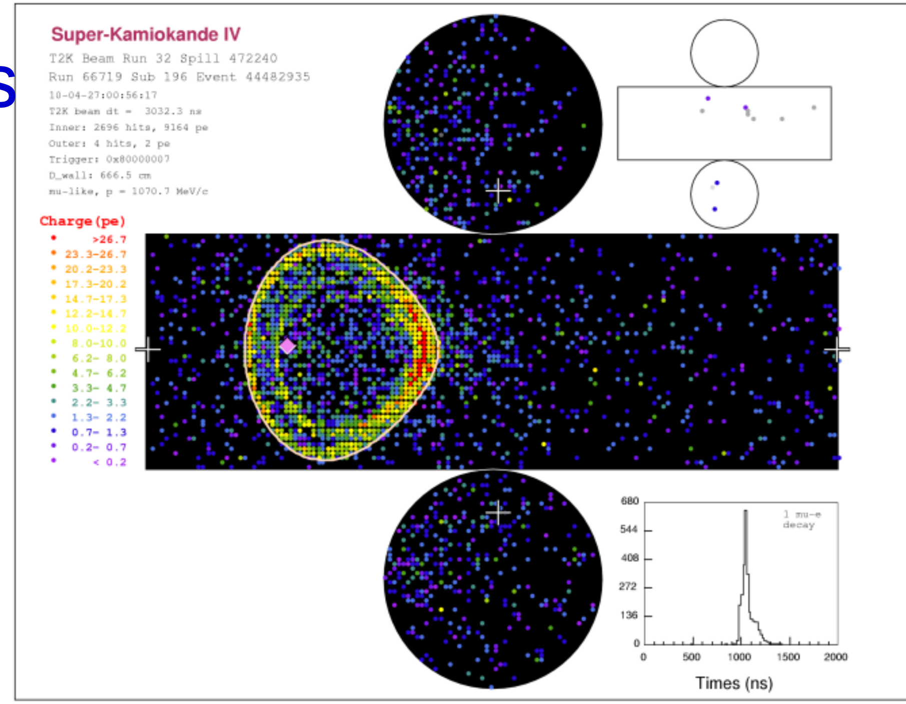
Event selection

Select ν_μ CC quasi-elastic events

- *Beam-timing*
- *Fully-contained, FV cut*
- *Single-ring & PID is muonlike*
- *Rec. μ momentum > 200 MeV/c*
- *# delayed electrons ≤ 1*

31 events selected

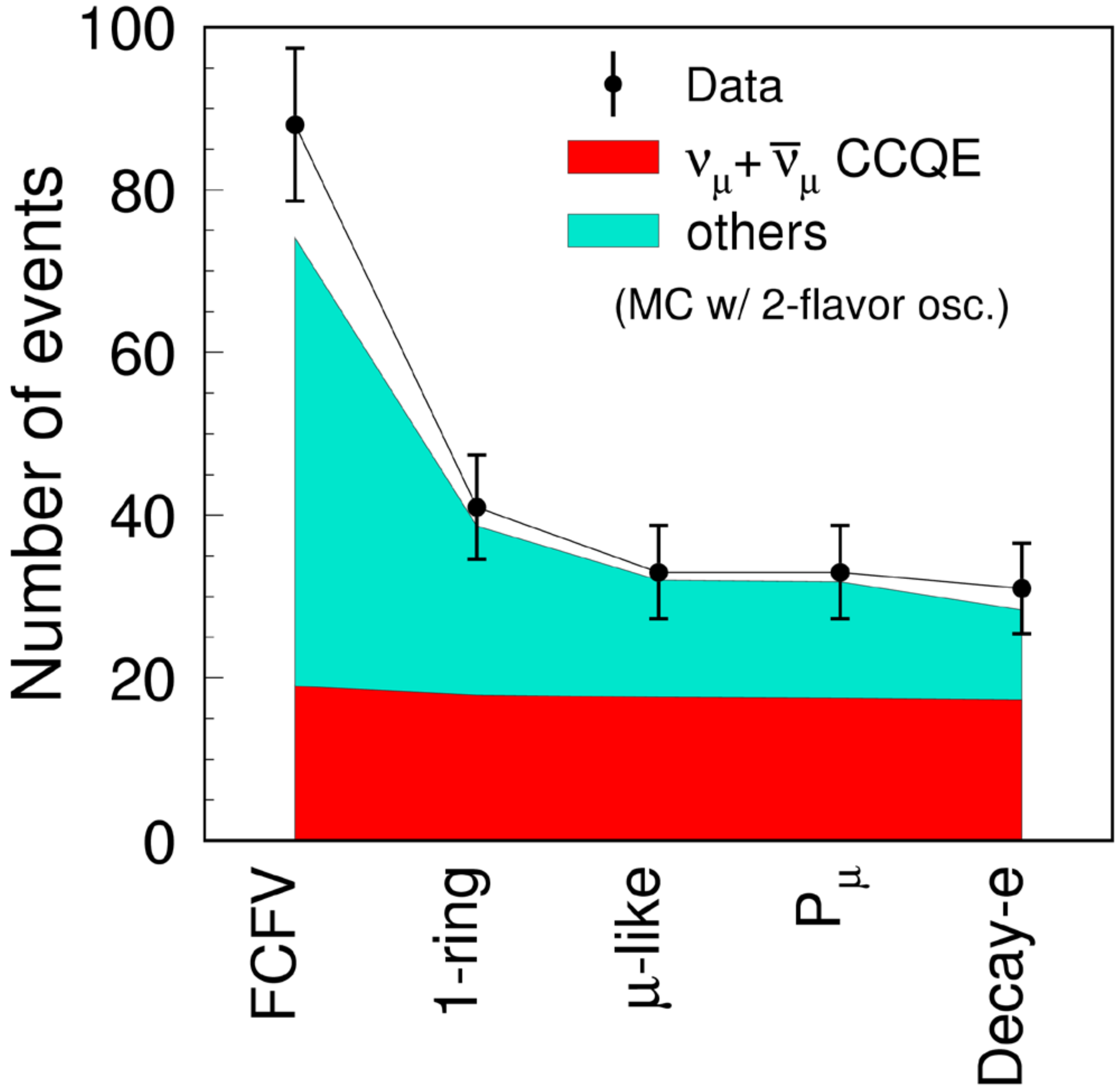
- *104 events expected w/o osc*
- *Neutrino energy reconstructed (E_ν^{rec}) with P_μ and θ_{beam}*



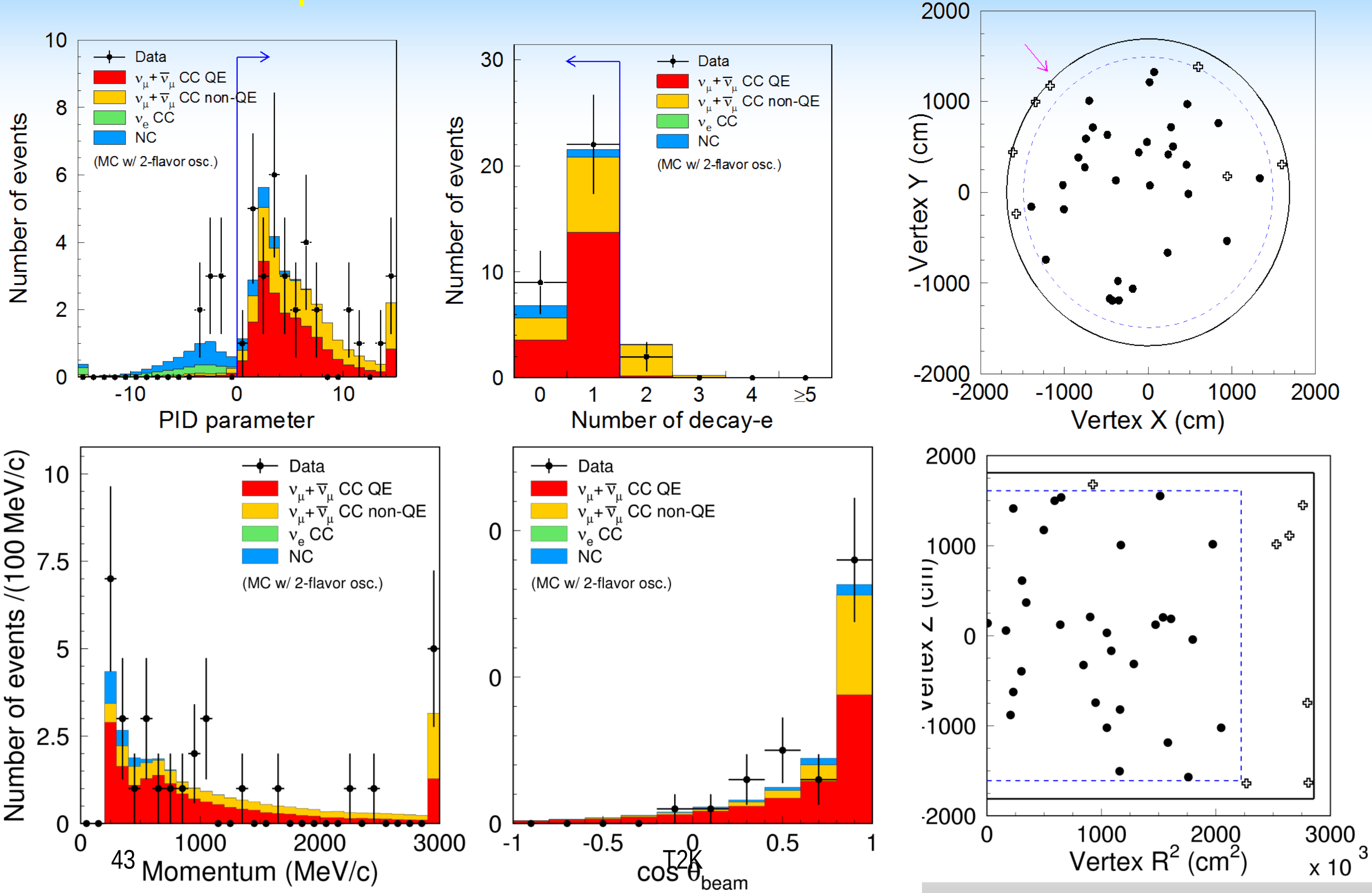
A selected single-ring μ-like event

Super-K muon selection

	Data	MC w/ 2-flavor oscillation					MC w/o osc.
		Total	ν_μCCQE	ν_μCC non-QE	ν_eCC	NC	
Interaction in FV	-	**141**	24.0	43.7	3.2	71.0	243
FCFV	**88**	**74.1**	19.0	33.8	3.0	18.3	166
Single-ring	**41**	**38.7**	17.9	13.1	1.9	5.7	120
μ-like	**33**	**32.0**	17.6	12.4	< 0.1	1.9	112
P_μ > 200 MeV/c	**33**	**31.8**	17.5	12.4	< 0.1	1.9	111
N(decay-e) ≤ 1	**31**	**28.4**	17.3	9.2	< 0.1	1.8	104
Efficiency	-	**20 %**	72 %	21 %	0.4 %	3 %	43 %


Number of events
100
80
60
40
20
0
Data
$\nu_\mu + \bar{\nu}_\mu$ CCQE
others
(MC w/ 2-flavor osc.)
FCFV
1-ring
μ-like
P_μ
Decay-e

T2K ν_μ event distributions



T2K

ν_μ Oscillation Analysis (Fitting)

Oscillation fit performed with 2-flavor oscillation assumption

$$P(\nu_\mu \to \nu_\mu) = 1 - \sin^2 2\theta \, \sin^2\left(1.27\Delta m^2 \frac{L}{E}\right)$$

$\chi^2 = -2\log\mathscr{L}$ is defined with # of events (N_{sk}) and E_ν^{rec} shape

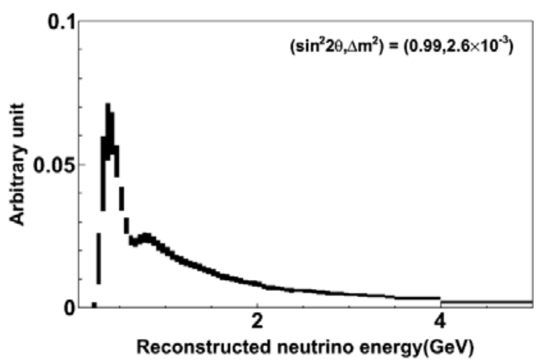
$$\mathscr{L} = \mathscr{L}_{norm} \times \mathscr{L}_{shape} \times \mathscr{L}_{sys} \qquad \chi^2 = -2\log\mathscr{L}$$

Method A : Un-binned maximum likelihood with systematic error parameter fitting

Method B : χ^2 for binned spectrum without systematic parameter fitting

Feldman-Cousins prescription is used for constructing confidence interval

E_ν^{rec} shape syst. errors w/ osci。



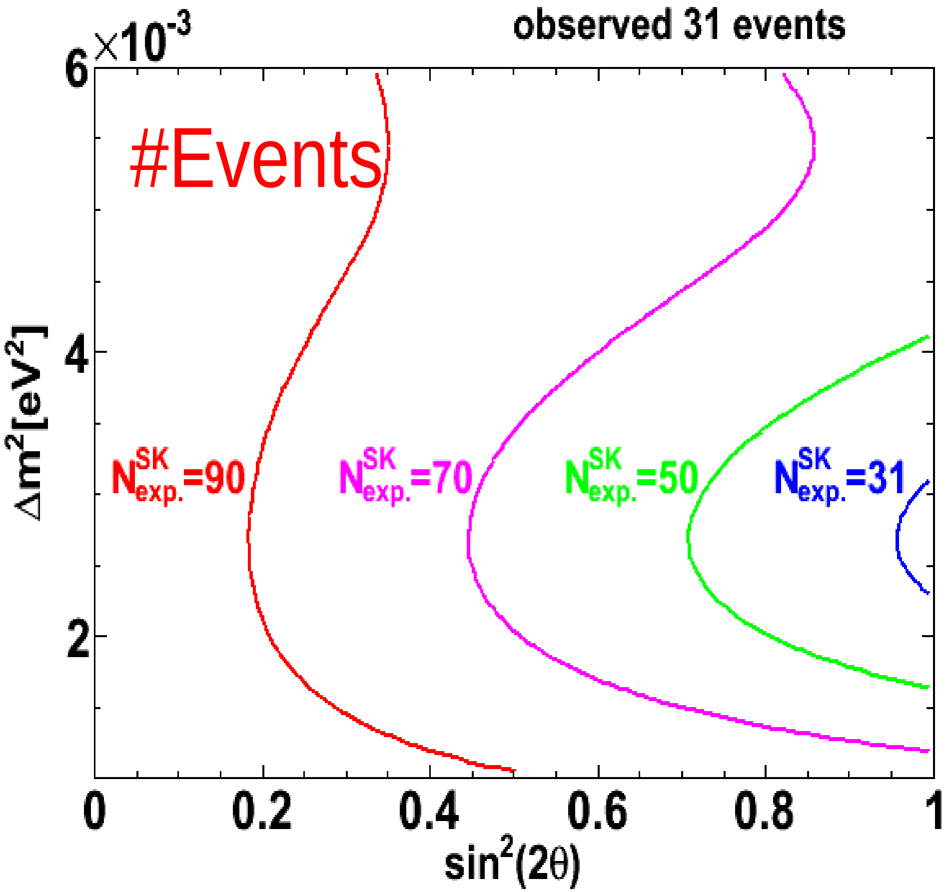
Assigned N_{sk} syst.

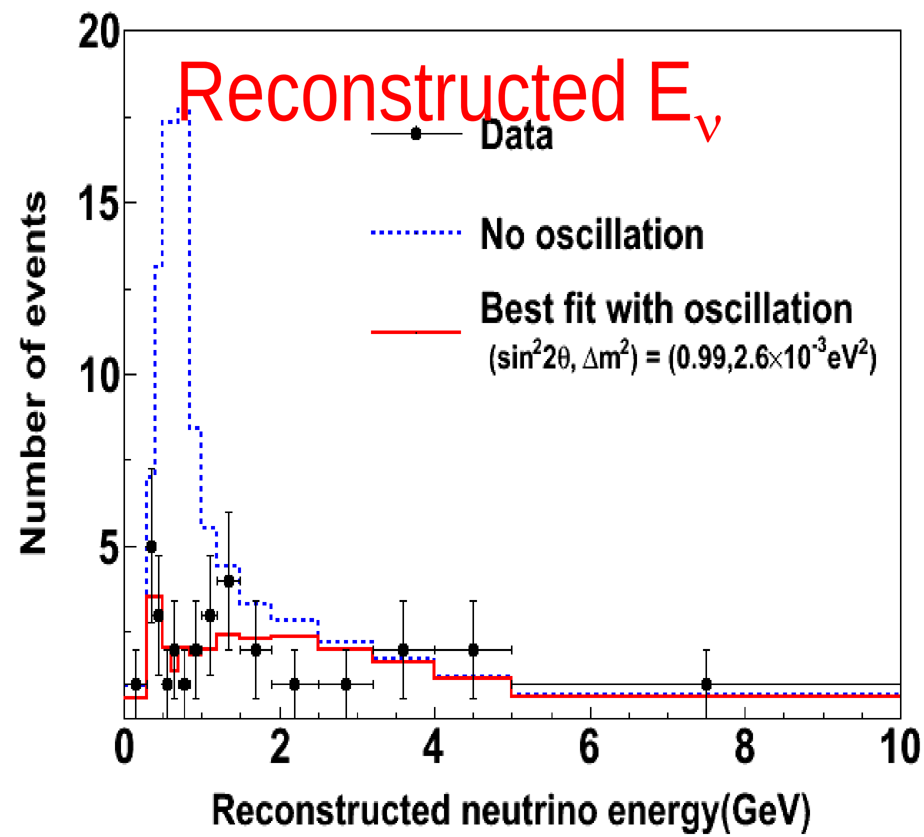
$N^{SK}_{exp.}$ error table

Error source	$\sin^2 2\theta = 1.0, \Delta m^2 = 2.4$	Null Oscillation
SK Efficiency	+10.3% 10.3%	+5.1% -5.1%
Cross section and FSI	+8.3% -8.1%	+7.8% -7.3%
Beam Flux	+4.8% -4.8%	+6.9% -5.9%
ND Efficiency and Overall Norm.	+6.2% -5.9%	+6.2% -5.9%
Total	+15.4% -15.1%	+13.2% -12.7%

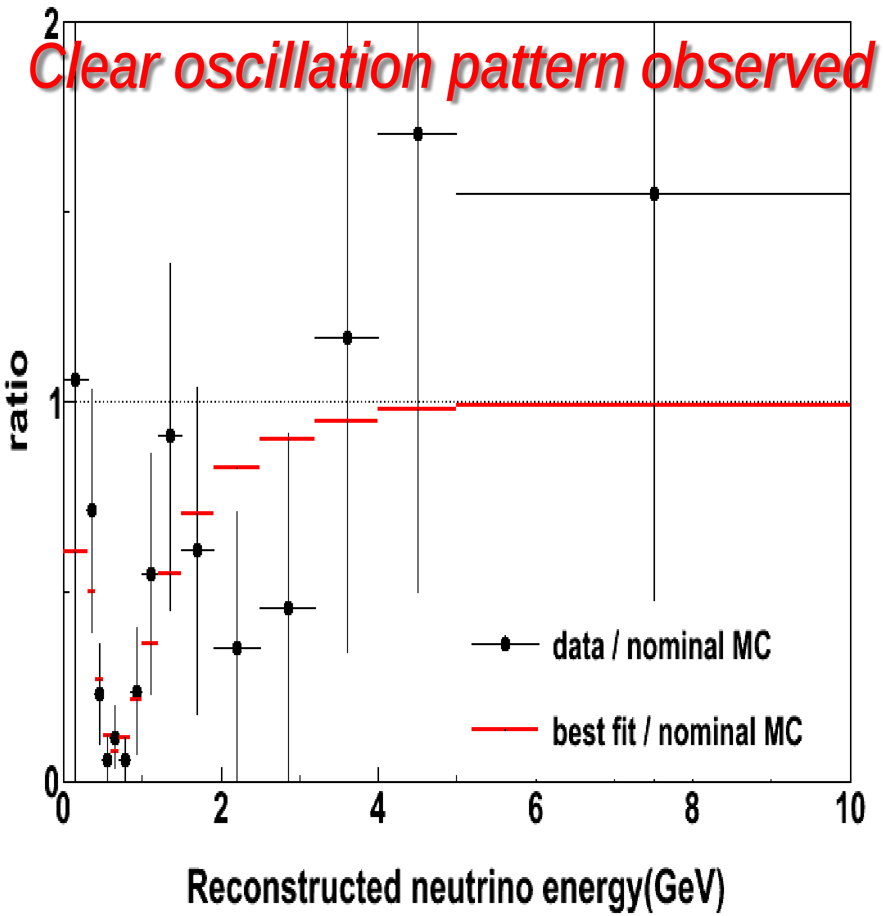
~15%

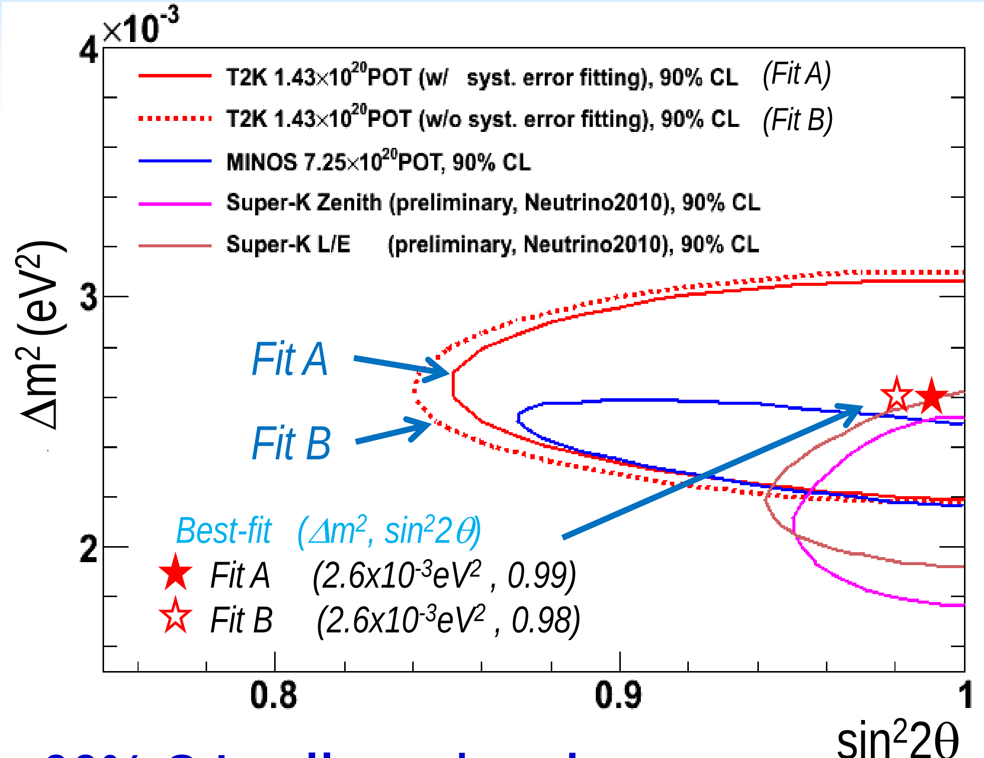
Oscillation Effects





Results





90% C.L. allowed region

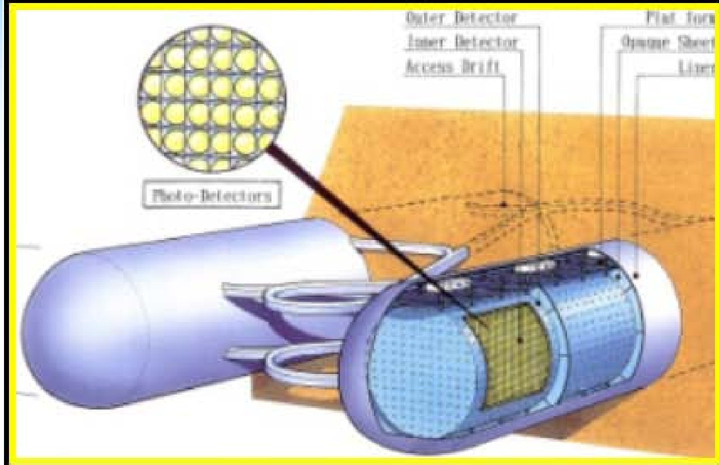
	Δm^2 (eV^2)	$\sin^2(2\theta)$
Fit A	2.1 ~ 3.1 x 10^{-3}	> 0.85
Fit B	2.1 ~ 3.2 x 10^{-3}	> 0.84

Consistent with MINOS/SK results

Future Prospect

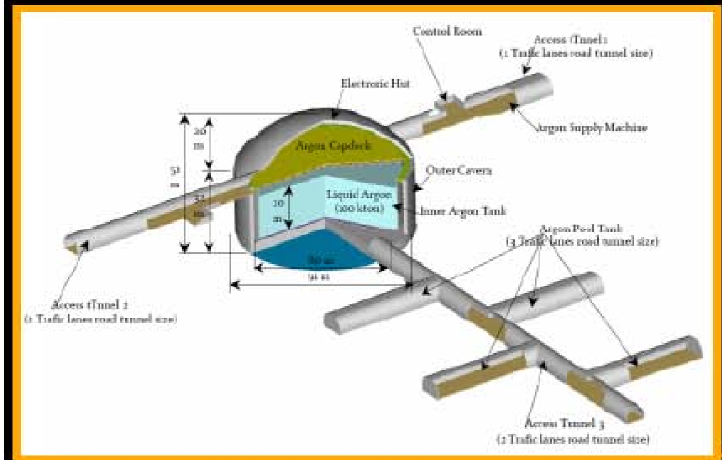
Beyond T2K

J-PARC+HK @ 神岡 L=295km OA=2.5deg

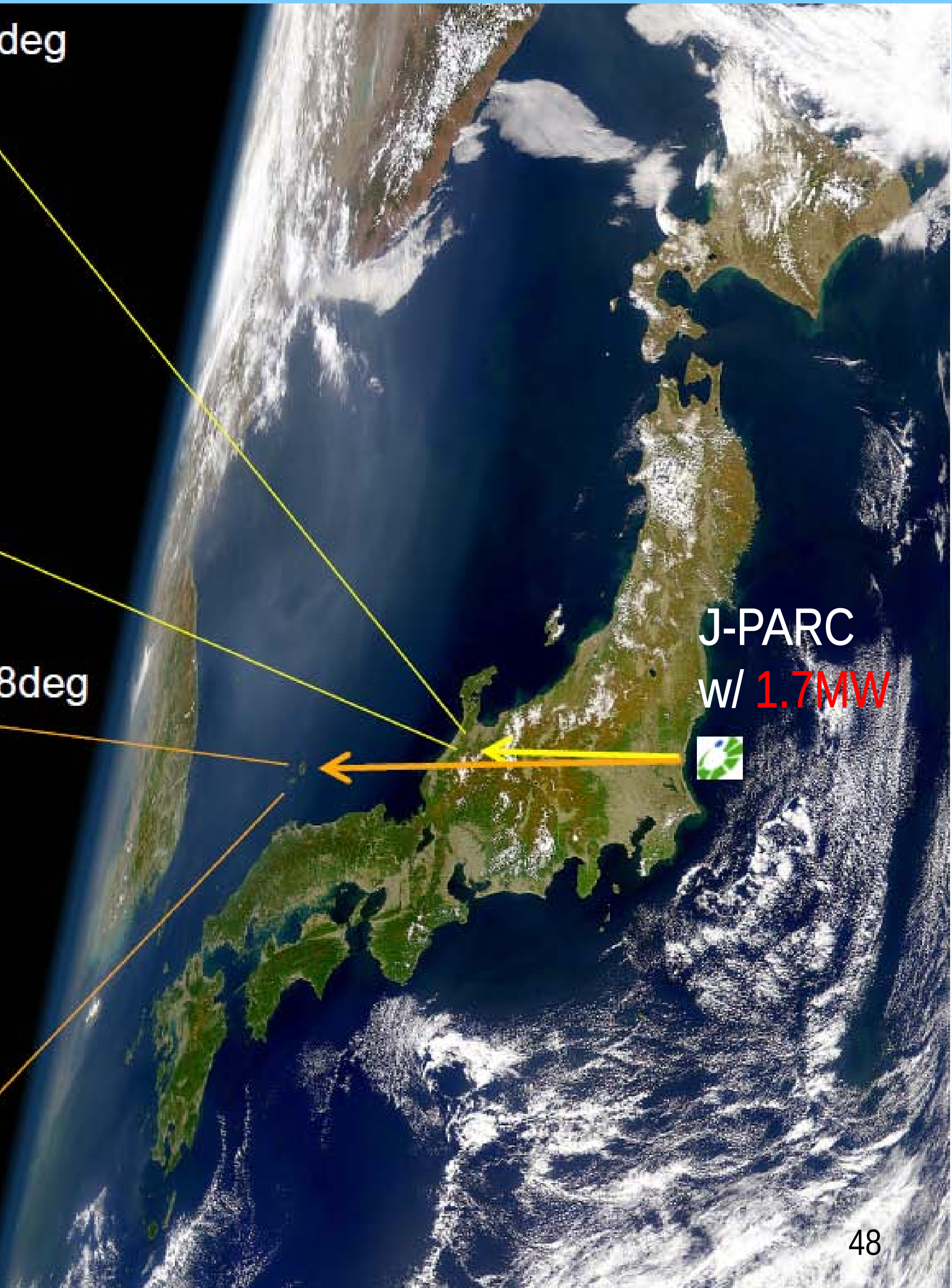


arXiv:: 1109.3262

J-PARC+LAr @ 隠岐 L=658km OA=0.78deg



P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
(Jan 2010), arXiv:0804.2111



Letter of Intent:

The Hyper-Kamiokande Experiment

— Detector Design and Physics Potential —

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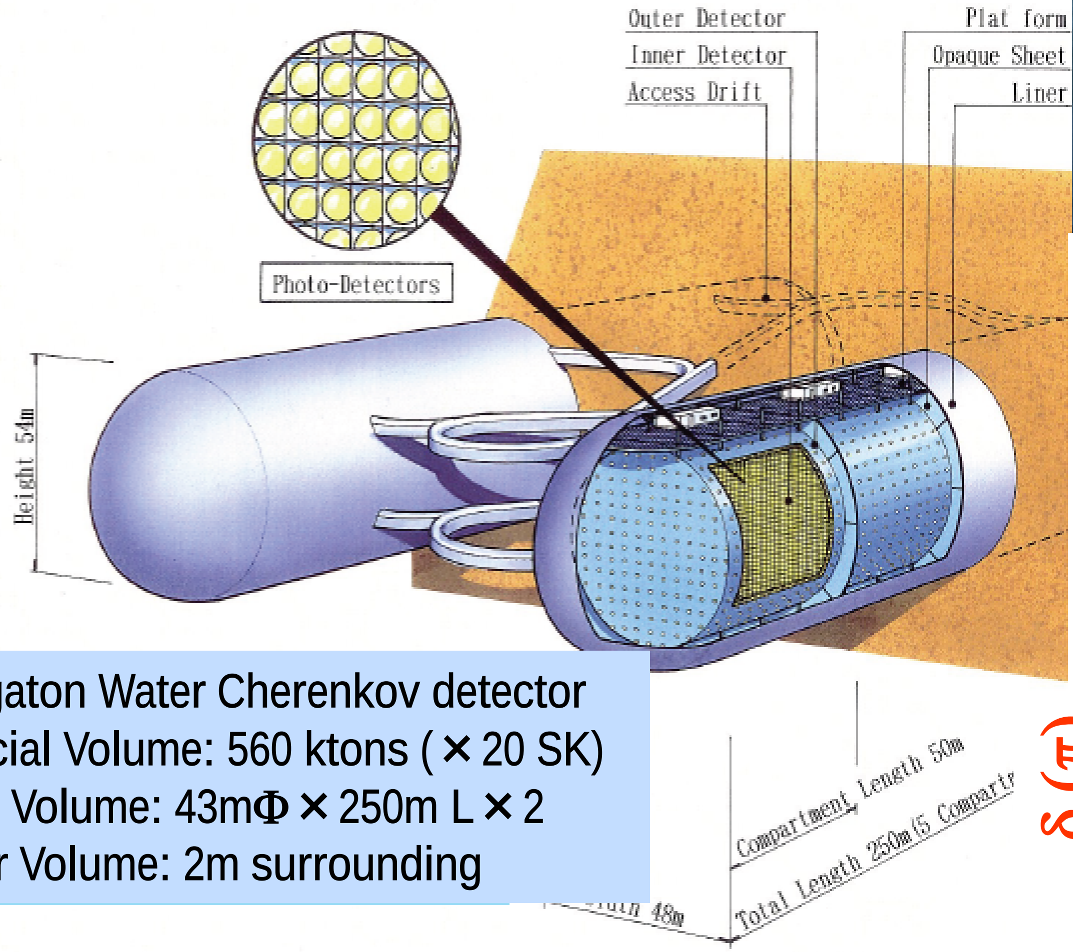
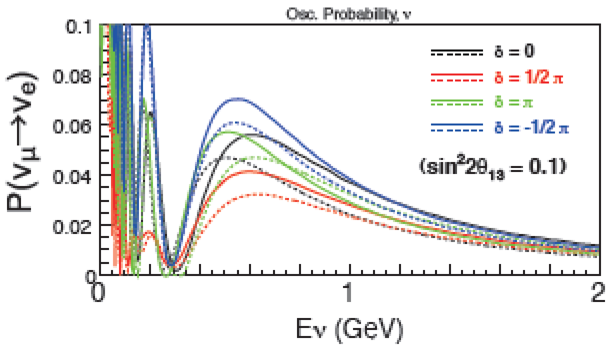
[10] *University of Tokyo, Department of Physics, Bunkyo, Tokyo 113-0033, Japan*

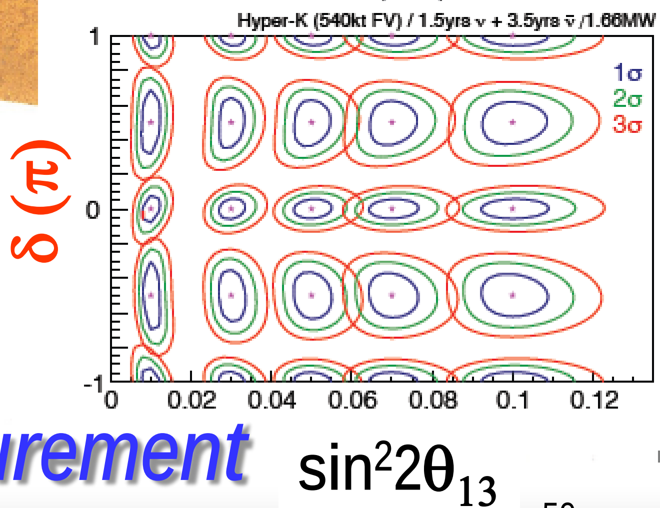
arXiv:1109.3262v1 [hep-ex] 15 Sep 2011

Hyper-Kamiokande

(The next generation Water Cherenkov detector)



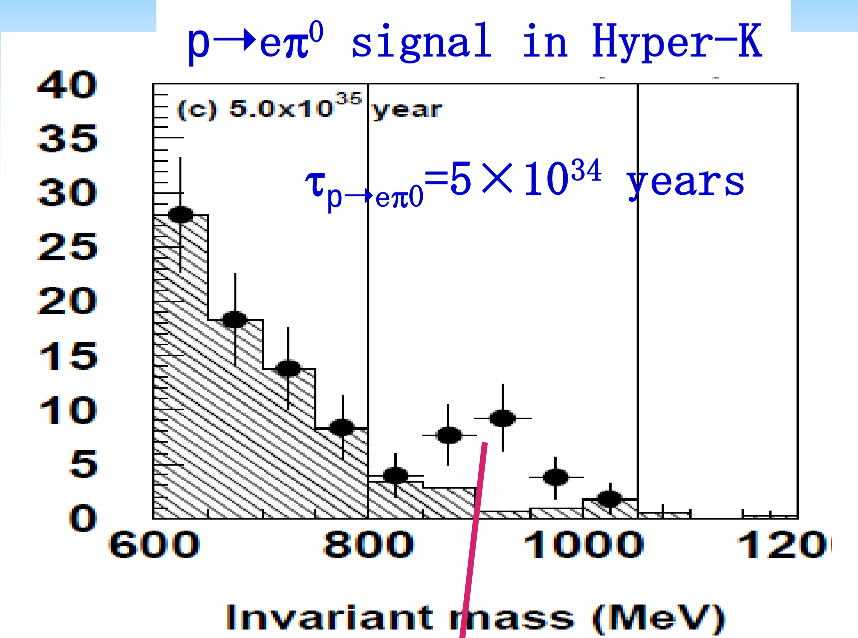


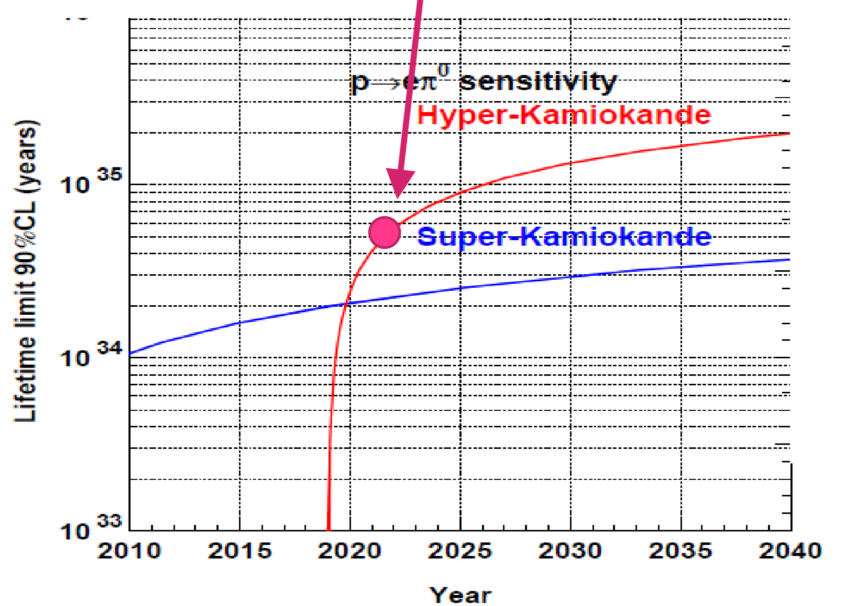


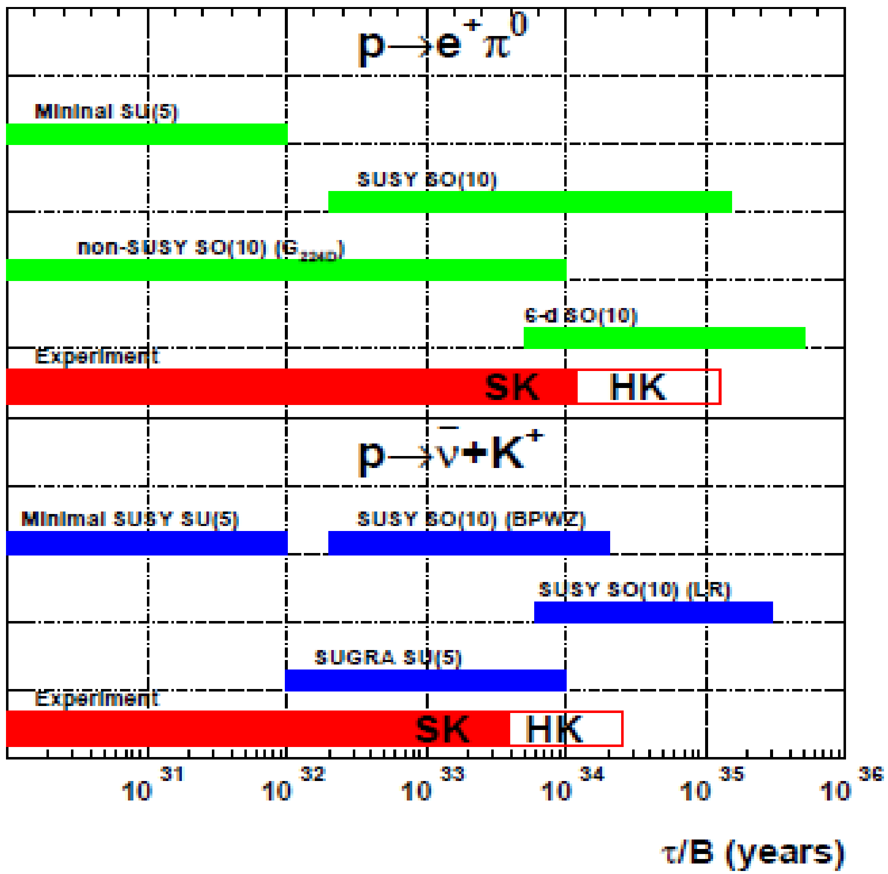
- 1 Megaton Water Cherenkov detector
- Fiducial Volume: 560 ktons (× 20 SK)
- Inner Volume: 43mΦ × 250m L × 2
- Outer Volume: 2m surrounding

ν CP violation measurement

Search for Proton decay to probe GUT

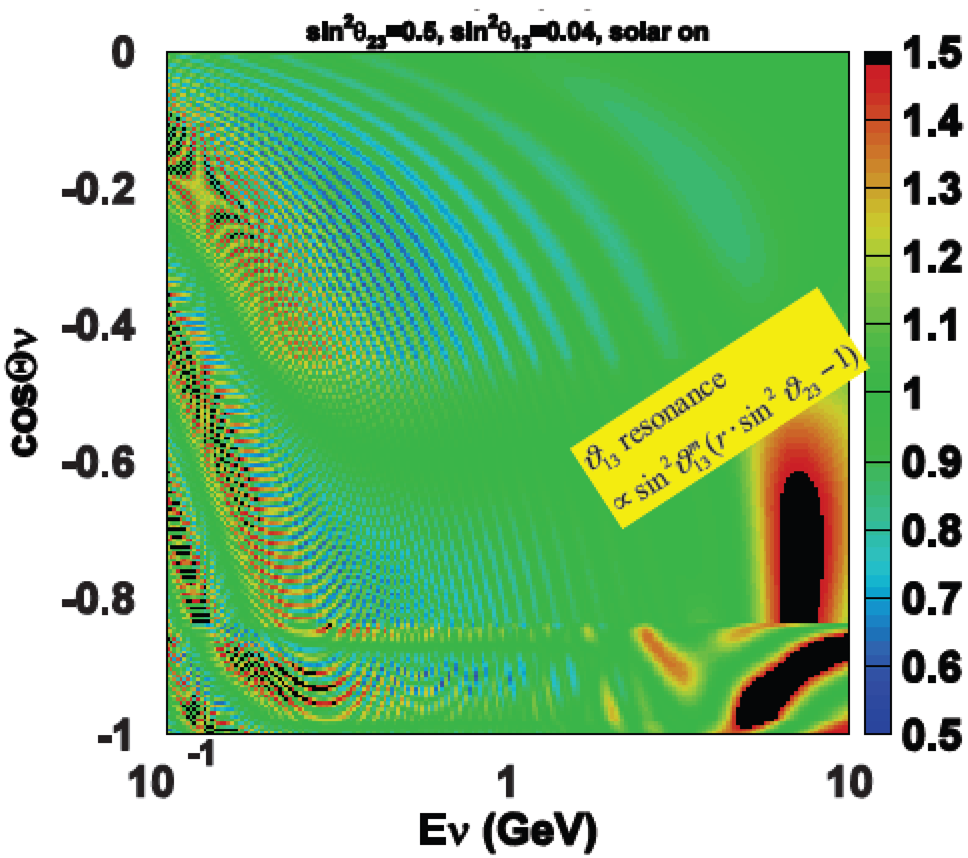


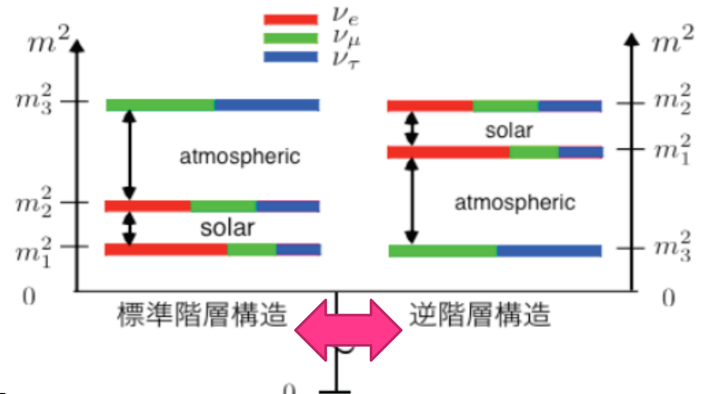


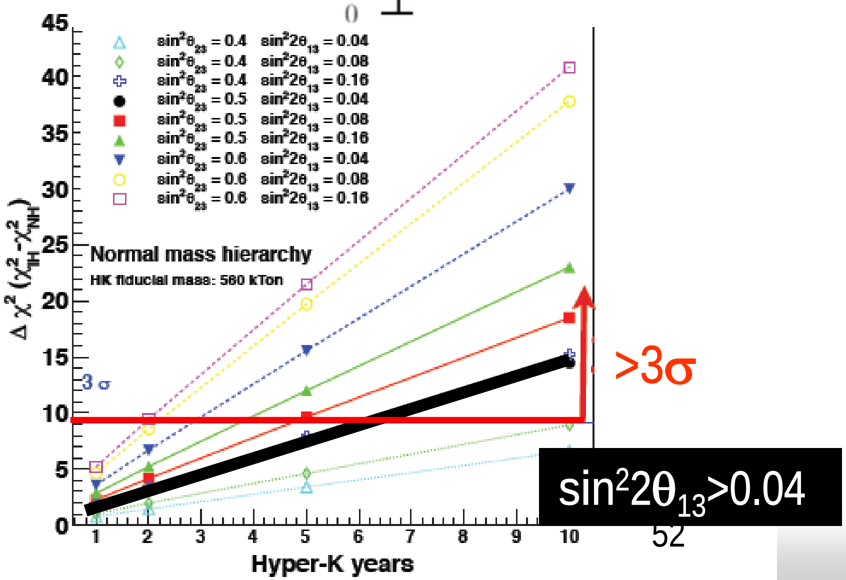


More physics in Hyper-K

- Astro-neutrinos (from Supernova and sun)
- Atmospheric neutrinos (ν_e appearance)
  - CPV, mass hierarchy, and θ_{23} >45° or <45°







J-PARC/T2K status and near future plan

J-PARC: Near LINAC


Just after earthquake


Just after earthquake

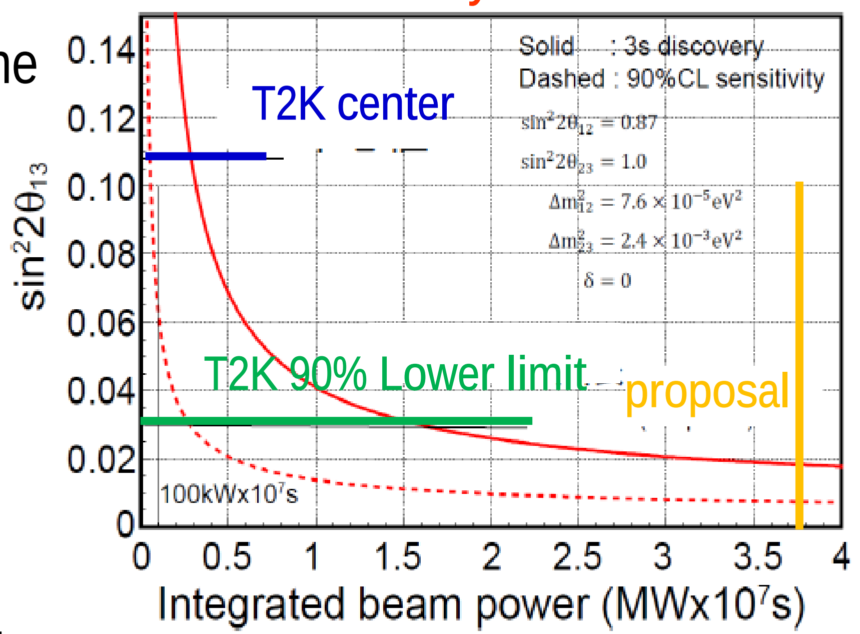

Now

J-PARC: Near RCS

T2K Near Future Plan

- By summer 2013: ~0.5 [MW × 10^7s]
  - 5 σ significance for $\sin^2 2\theta_{13}$=0.11 (T2K central value)
- Within several years: ~1 [MW × 10^7s]
  - 3 σ significance for $\sin^2 2\theta_{13}$=0.04 (near the T2K 90% Lower limit)
- Proposal: 3.8 [MW × 10^7s]
  - 3 σ significance for $\sin^2 2\theta_{13}$=0.02
- Analysis Improvements
  - More SK event information（E_ν^{rec}, etc..)
  - More Near Detector measurements（E_ν spectrum, ν cross section measurements, etc..）。
  - Improvement of beam simulation (including NA61 Kaon data, etc..)
  - More..

T2K sensitivity versus beam



Summary

- T2K accumulated and analyzed 1.43×10^{20} POT data from January 2010 to March 11th 2011.
  - ν_e appearance
    - ν_e Observation：6
    - Estimation：1.5±0.3 （for $\sin^2 2\theta_{13}=0$）
      - 0.7% probability（2.5σ significance）
    - ***Indication of $\nu_\mu \rightarrow \nu_e$ appearance***
    - Published in Phys. Rev. Lett. 107, 041801 (2011)
  - ν_μ disappearance
    - Observation of large ν_μ disappearance
    - Measured the neutrino oscillation parameters with the world-best level precision.

- *J-PARC will start in Dec. 12th, 2011. T2K is ready to start!*

The XXV International Conference on Neutrino Physics and Astrophysics
June 3-9 2012
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NAKAHATA Masayuki (ICRR, Tokyo/IPMU) [co-chair]
KOBAYASHI Takashi (KEK) [co-chair]