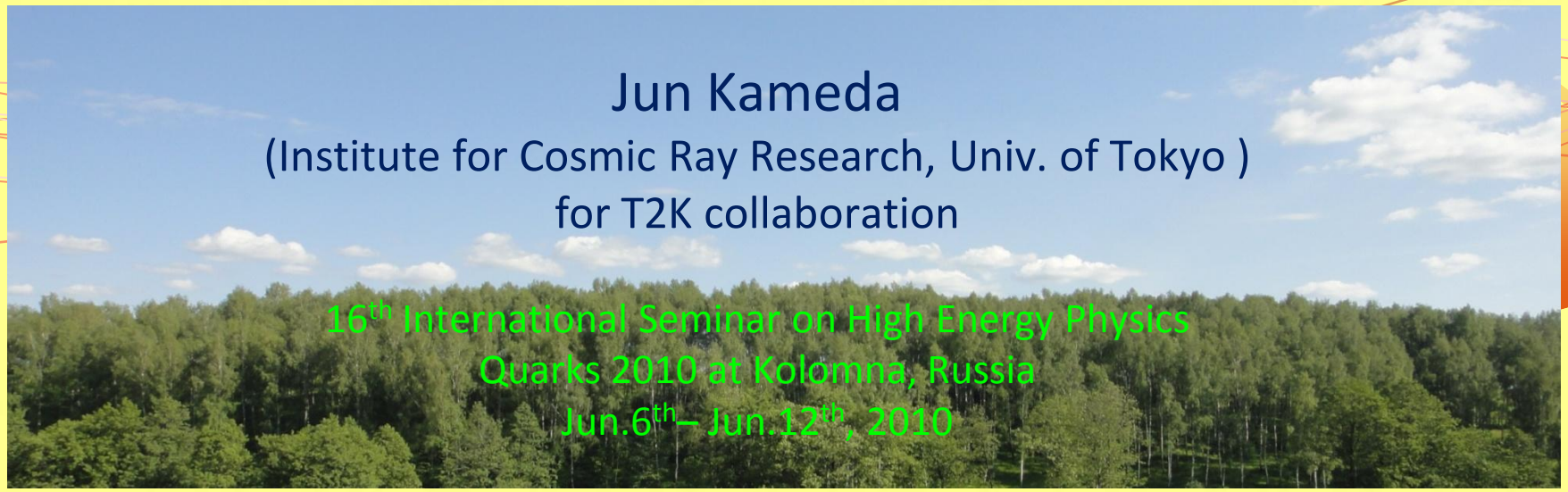
Overview and Status of T2K experiment



Jun Kameda
(Institute for Cosmic Ray Research, Univ. of Tokyo)
for T2K collaboration

16th International Seminar on High Energy Physics
Quarks 2010 at Kolomna, Russia
Jun.6th– Jun.12th, 2010

Outline

- Introduction of T2K experiments
- Physics Goal
- Experimental setup & status
- Summary

T2K collaboration

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

France
CEA Saclay
IPN Lyon
LLR E.Poly
LPNHE Paris

Germany
U.Aachen

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

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

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

Russia
INR

S.Koria
N.U.Chonnam
U.Dongshin
U.Sejong
N.U.Seoul
U.Sungkyunkwan

Spain
IFIC, Valencia
U.A.Barcelona

Switzerland
U.Bern
U.Geneva
ETH Zurich

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

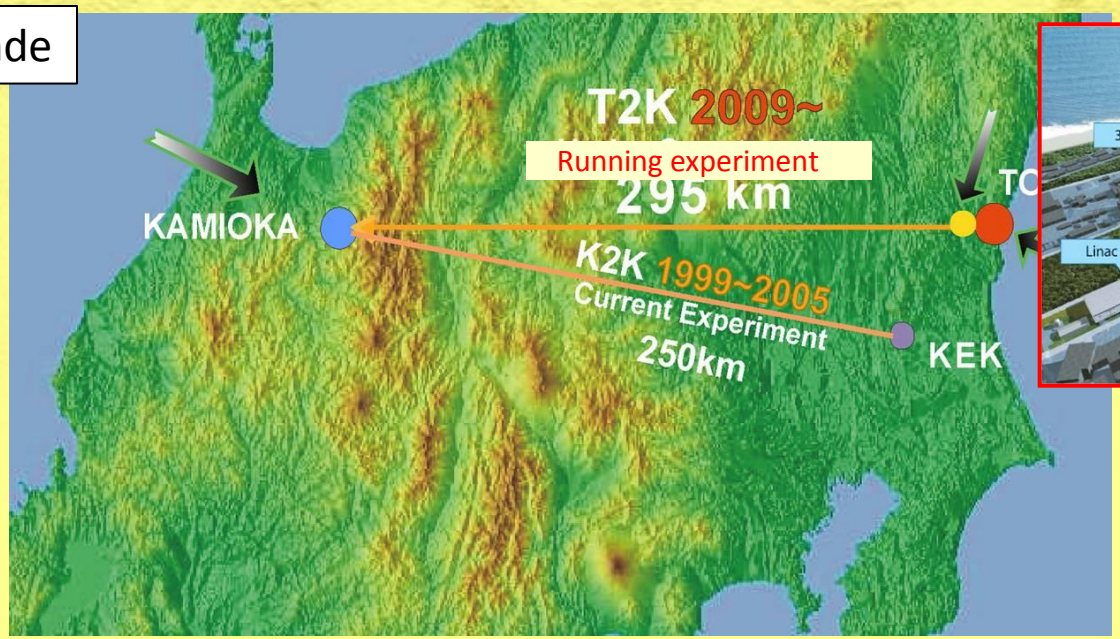
U.S.A.
Boston U.
B.N.L.
Colorad S.U.
Duke U.
Louisiana S.U.
Stony Brrok U
U.C.Irvine
U.Colorado
U.Pittsburgh
U.Rochester
U.Washington

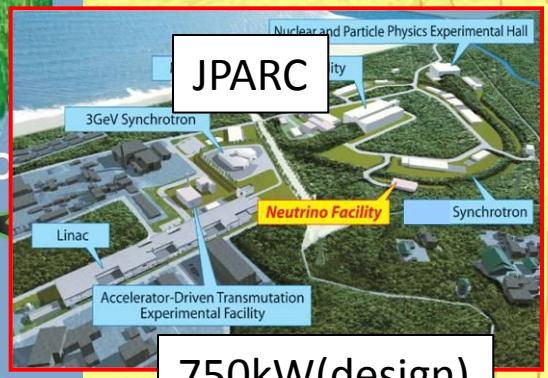
- 62 Institute from 12 Countries,, ~500 physicists.

T2K (Tokai to Kamioka) Long Baseline ν oscillation experiment

First Long baseline ν oscillation experiment using High intensity off-axis ν beam

Super-Kamiokande





- High intensity neutrino beam from JPARC.
- Quasi monochromatic off-axis neutrino beam is used. (Energy is tuned to oscillation maximum energy at 295km).
- Super-Kamiokande as far detector, Newly made near neutrino detectors

Physics Goal:

- Discovery of $\nu_\mu \rightarrow \nu_e$ oscillation
- Precise measurement of ν_μ disappearance

Milestones

- 2001 ● "The JHF-Kamioka neutrino project" was published.
- 2004 ● Experiment officially approved. Start construction.
- Mar.2009 ● Construction completed.
- Apr.2009 ● First neutrino beam
- Jan.2010 ● Started physics run. $\nu_\mu \rightarrow \nu_e$ search started!
- Feb.2010 ● First T2K neutrino event at Super-Kamiokande !

Introduction: Neutrino Oscillation

Flavor eigenstates are mixture of mass eigenstates:
(Maki-Nakagawa-Sakata-Pontecorvo Matrix)

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = U_{\alpha i}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix} = \begin{pmatrix}1 & 0 & 0\\ 0 & \cos\theta_{23} & \sin\theta_{23}\\ 0 & -\sin\theta_{23} & \cos\theta_{23}\end{pmatrix}\cdot\begin{pmatrix}\cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -\sin\theta_{13}e^{-i\delta} & 0 & \cos\theta_{13}\end{pmatrix}\cdot\begin{pmatrix}\cos\theta_{12} & \sin\theta_{12} & 0\\ -\sin\theta_{12} & \cos\theta_{12} & 0\\ 0 & 0 & 1\end{pmatrix}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Flavor eigenstates

Atmospheric ν,
Accelerator ν experiments
(K2K, MINOS, T2K..)

$\theta_{23} \sim 45^\circ$
$\Delta m^2_{23} \sim 2.5\times10^{-3}(eV^2)$

Reactor ν,
Accelerator ν,
Atm. ν

$\sin^2 2\theta_{13} < 0.14$
Only Upper limit

Solar ν,
Reactor ν

$\theta_{12} \sim 34^\circ$
$\Delta m^2_{12} \sim 8\times10^{-5}(eV^2)$

$\left(\Delta m^2_{ij} = m^2_i - m^2_j\right)$

Mass eigenstates

Physics goal of T2K:

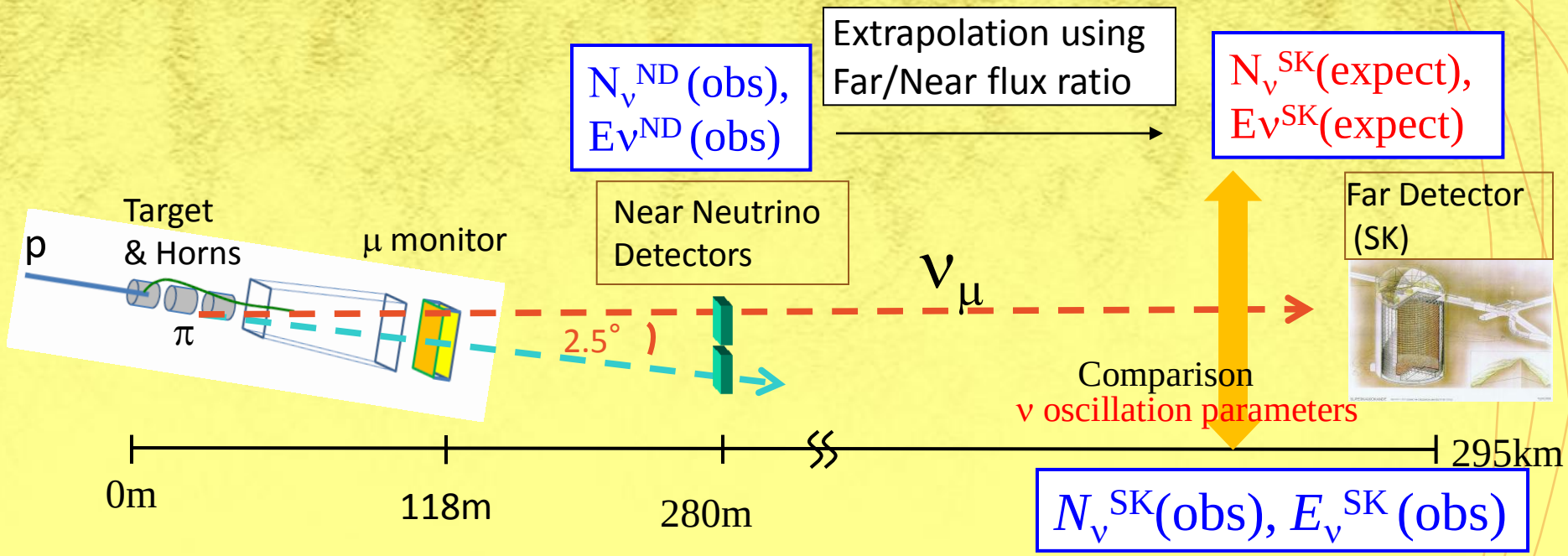
- Measure finite θ_{13} by ν_e appearance search:

$$P(\nu_\mu \to \nu_e) \approx \sin^2 2\theta_{13}\sin^2\theta_{23}\sin^2\left(1.27\Delta m^2_{13}L/E\right)$$

- Precise measurement of θ_{23}, Δm^2_{23} by ν_μ disappearance

$$P(\nu_\mu \to \nu_\mu) \approx 1-\sin^2 2\theta_{23}\sin^2\left(1.27\Delta m^2_{23}L/E\right)$$

Principle of T2K experiment



- Compare Observed number of events and Eν spectrum in Super-K with expected values, and extract neutrino oscillation parameters.
- Expected values at SK are obtained from Near Detector Measurements by extrapolation using "Fart to near ratio", *R(SK/ND)*.
  - $N\nu_e^{sk}$ (expected)= $P(\nu_\mu \rightarrow \nu_e)$ x R(SK/ND) × $N\nu_\mu^{ND}$(obs.)
  - $N\nu_\mu^{sk}$ (expected)= $P(\nu_\mu \rightarrow \nu_\mu)$ x R(SK/ND) × $N\nu_\mu^{ND}$(obs.)

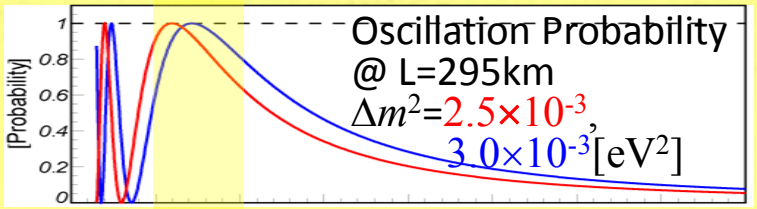
Near Detector Measurement

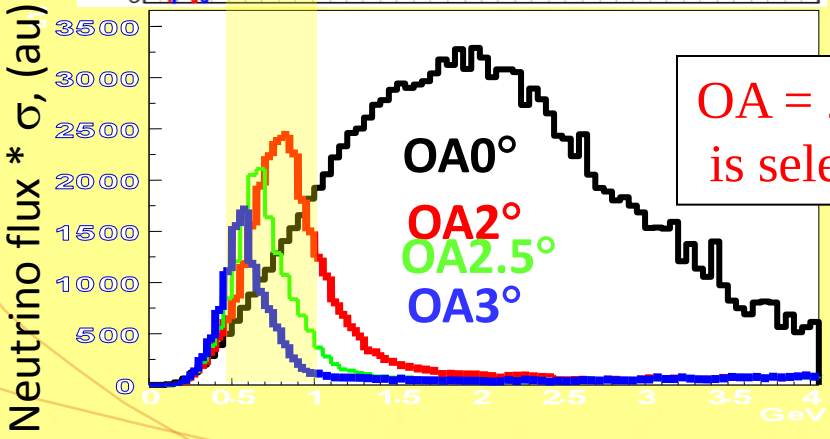
Principle (cont'd)

- Far to Near flux ratio, *R(SK/ND),* is estimated by "beam MC".
- A detailed MC simulation of T2K neutrino beam (beam MC) has been developed.
  - Inputs to beam MC for Tuning
    - Targeting condition: Measured values by proton beam monitors.
    - Horn focusing effect, geometrical acceptance.
    - π,K kinematics: From CERN NA61 experiment.
- Event selection is done by GPS timing (will be discussed after.)

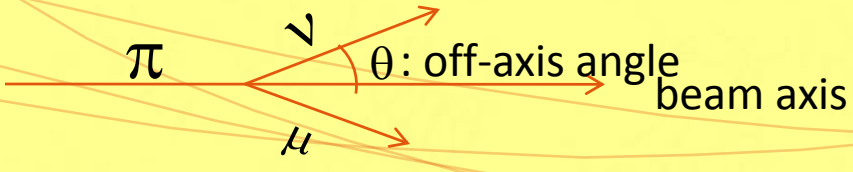
Off-axis beam

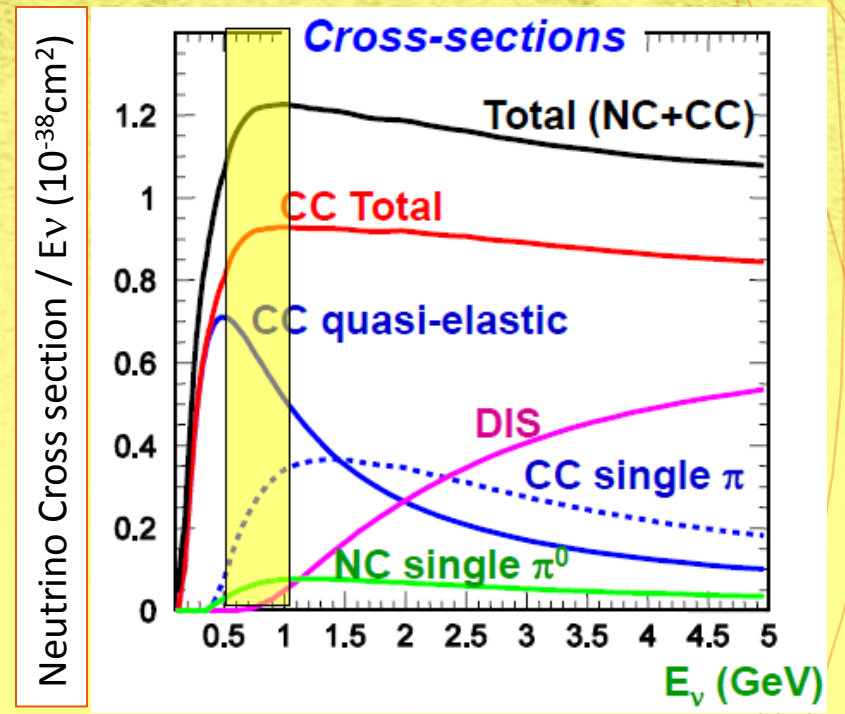
- Neutrino Energy has angle dependence from beam axis.
- Pseudo-monochromatic neutrino beam with finite off-axis.





OA = 2.5° is selected.





- Dominant interaction is Charged Current (CC) Quasi-elastic (Q.E.) scattering:

$$\nu_\mu\,(\nu_e) + n \rightarrow \mu(e) + p$$

- Reducing B.G.s from inelastic processes.

Physics Goal of T2K

1. First observation of $\nu_\mu \rightarrow \nu_e$ oscillation

Search for appearance of ν_e by electron signal from CC Q.E. scattering of ν_e:

$$\nu_e + n \rightarrow e^- + p$$

Background events:

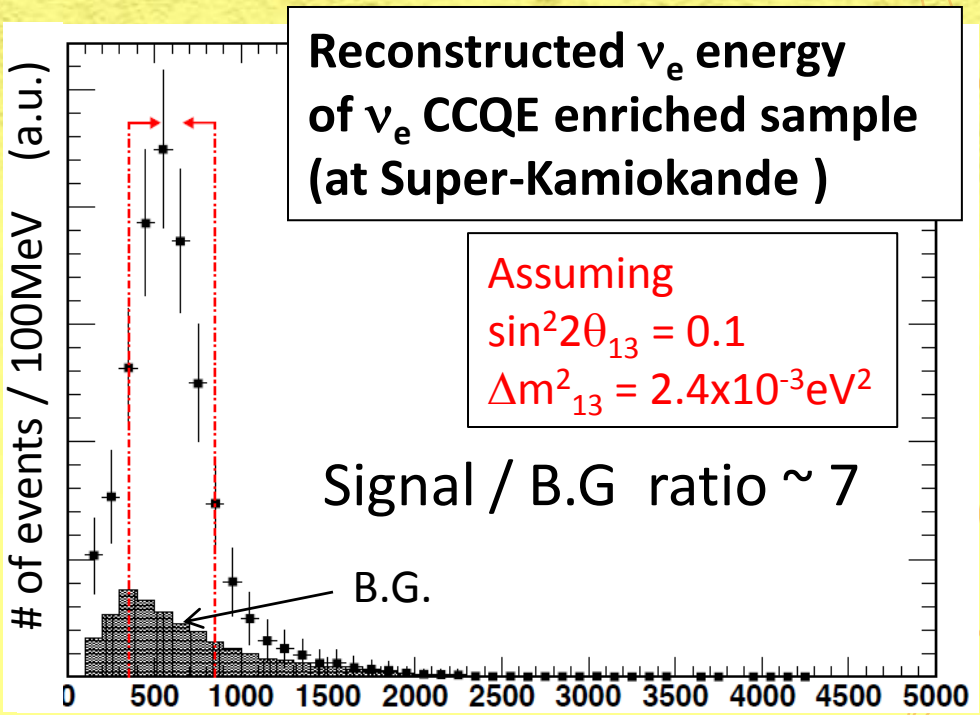
- Beam ν_e induced events:

  $\nu_e + n \rightarrow e^- + p$

- NC π^0 production:

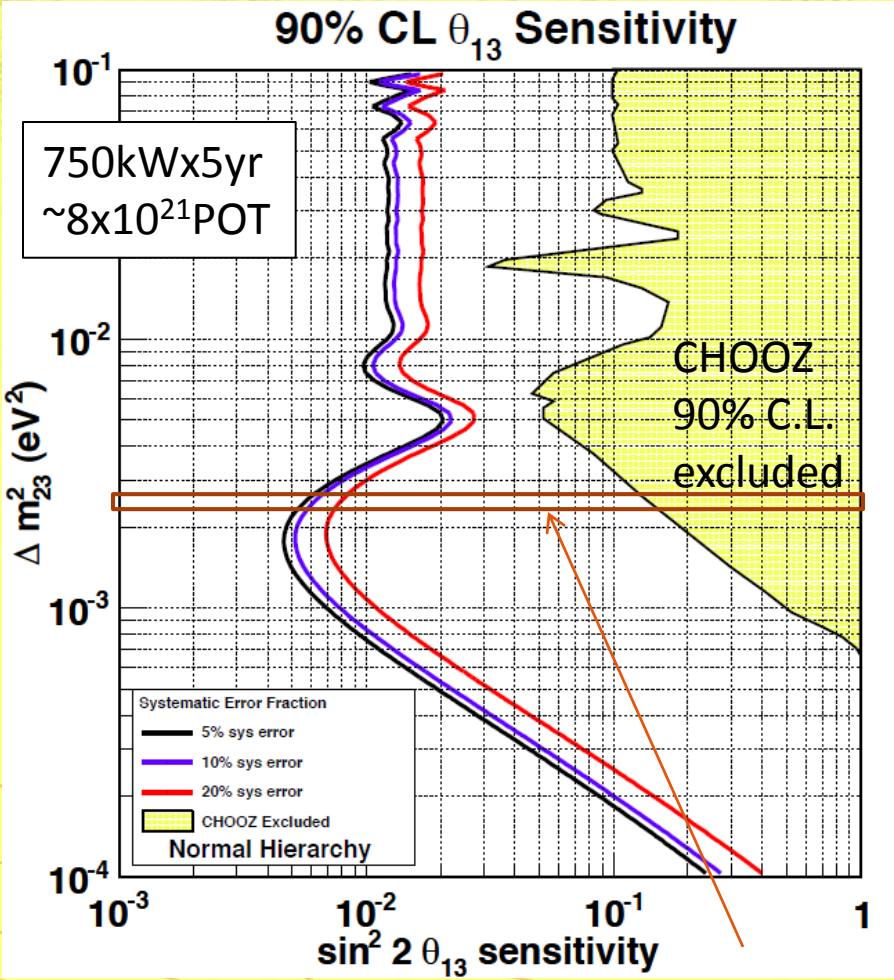
  $\nu + N \rightarrow \nu + N + \pi^0$

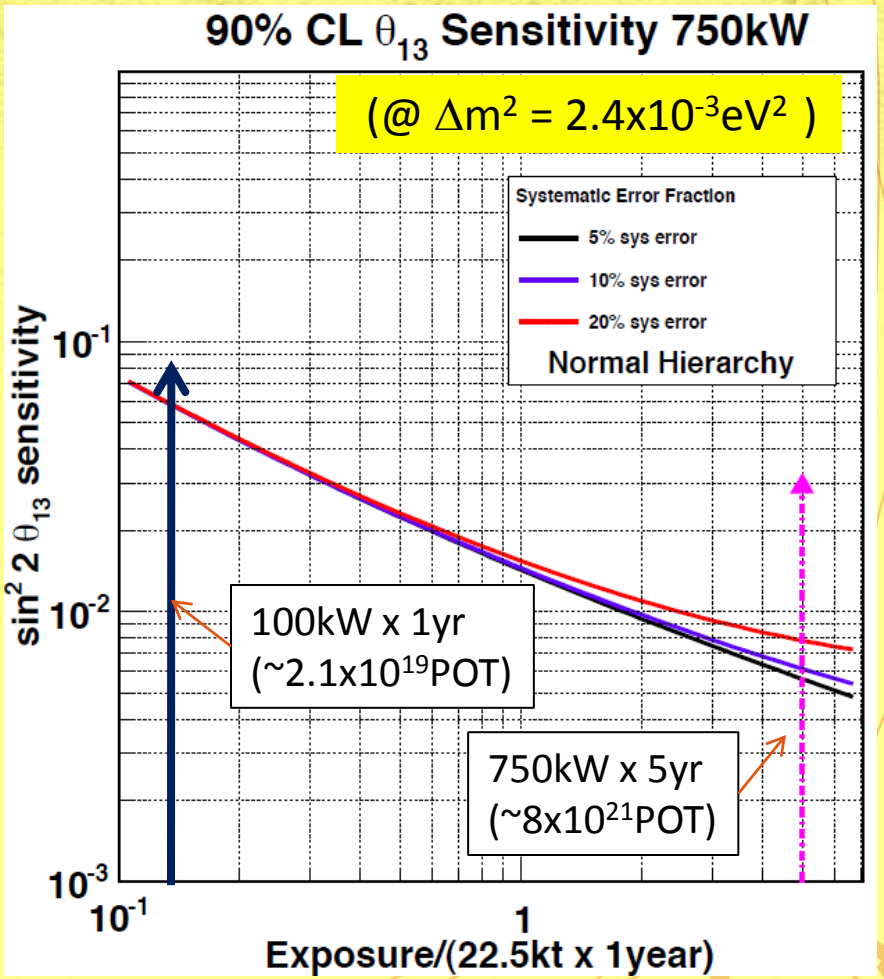
  $\pi^0 \rightarrow \gamma + \gamma$



ND measurement of beam ν_e flux, π^0 production rate will reduce systematic uncertainty of B.G. rate.

Sensitivity to θ_{13}





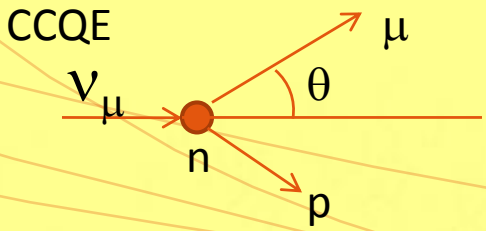
Sensitivity ~0.006
@ $\Delta m^2 = 2.4 \times 10^{-3} eV^2$

Physics Goal of T2K

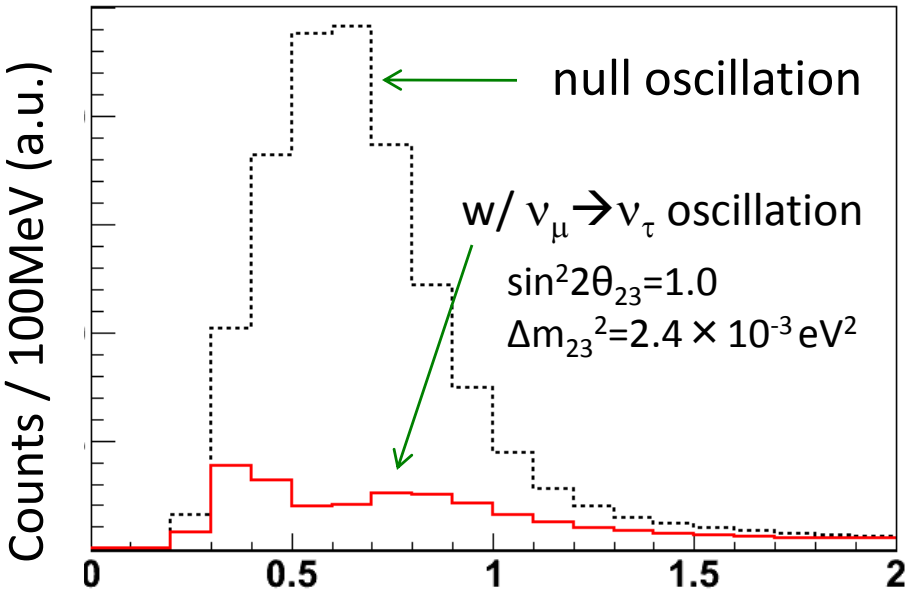
2. Precise measurement of ν_μ disappearance

Neutrino Oscillation induce a distortion of energy of muon neutrinos.
CCQE enriched sample is used to reconstruct Eν assuming 2-body interaction:

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



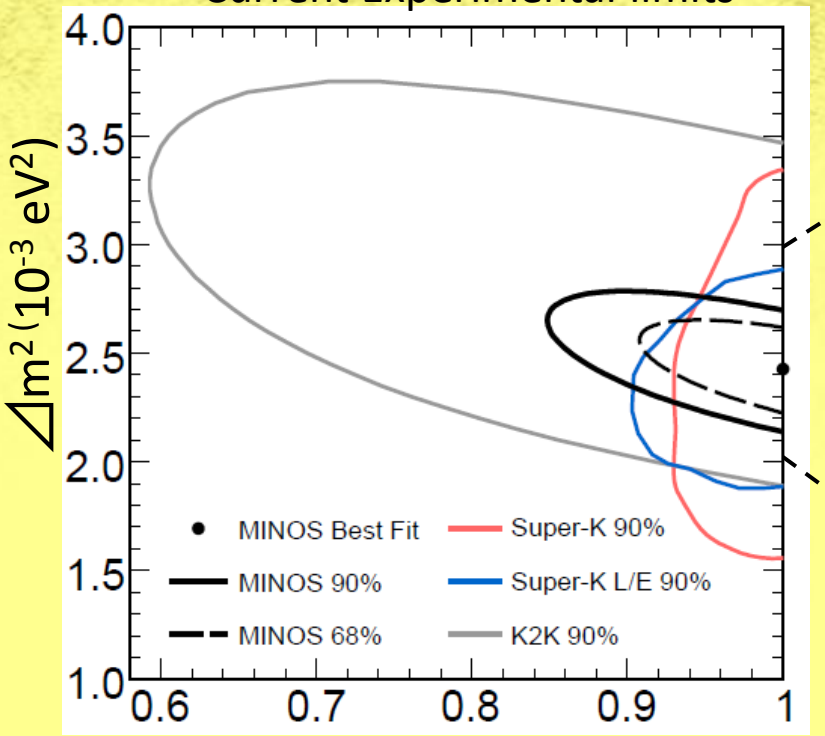
Reconstructed ν_μ energy of ν_μ CCQE enriched sample (at Super-Kamiokande)

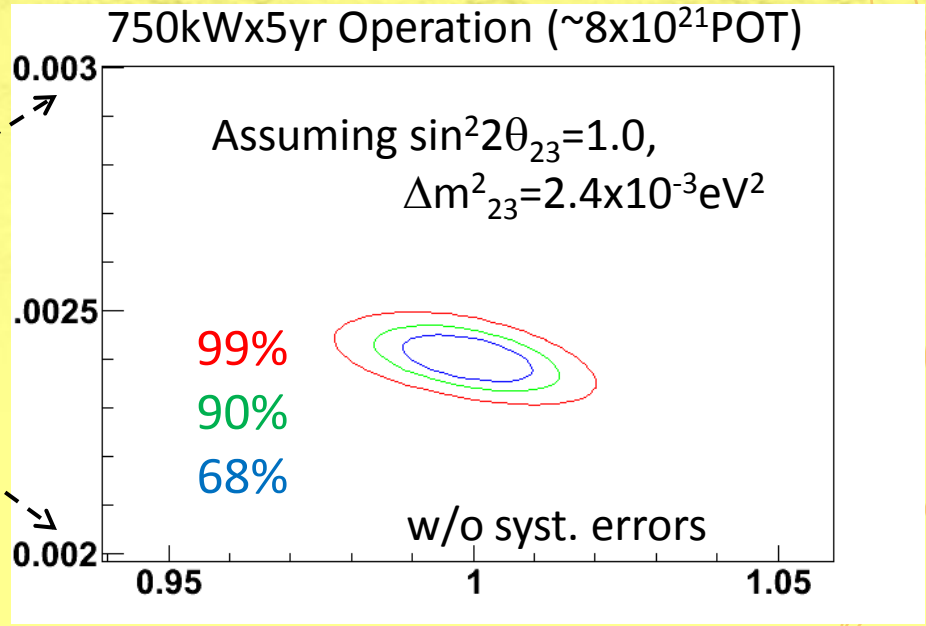


Dip of the neutrino oscillation at $E_\nu \sim 600$MeV.

Sensitivity to θ_{23} & Δm_{23}

Current Experimental limits

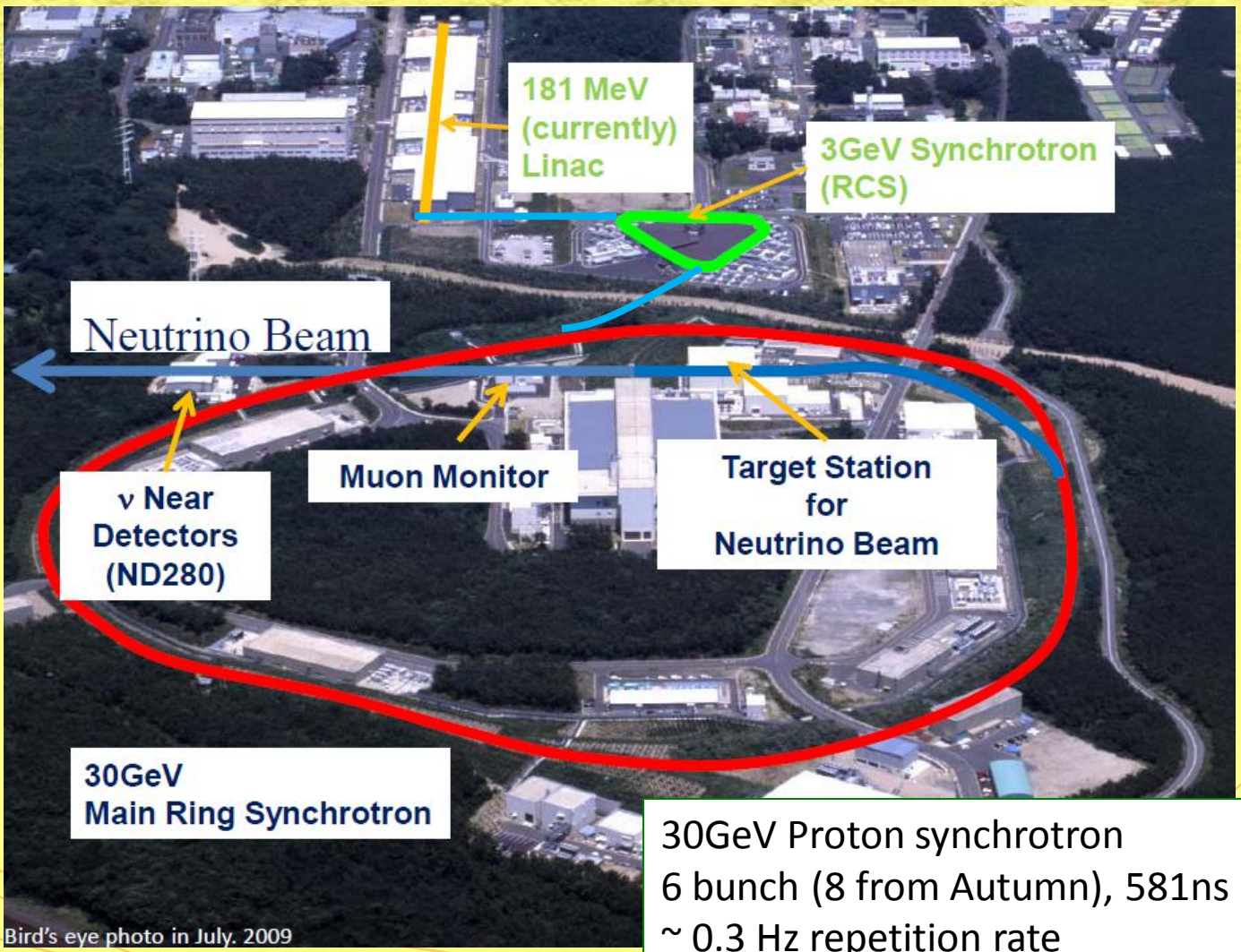




Very precise measurements

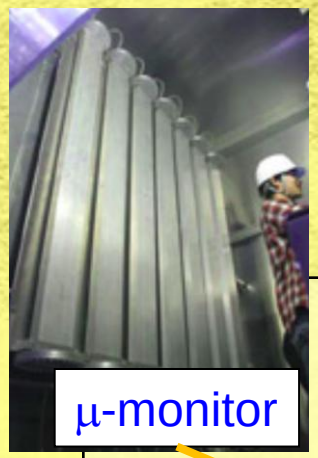
Our goal: $\delta(\Delta m^2_{23}) \sim 1\text{x}10^{-4}\text{eV}^2$
$\delta(\sin^2 2\theta_{23}) \sim 0.01$

Experimental setup: J-PARC Accelerator and Experimental Facility



30GeV Proton synchrotron
6 bunch (8 from Autumn), 581ns interval
~ 0.3 Hz repetition rate
Construction finished 2008 JFY

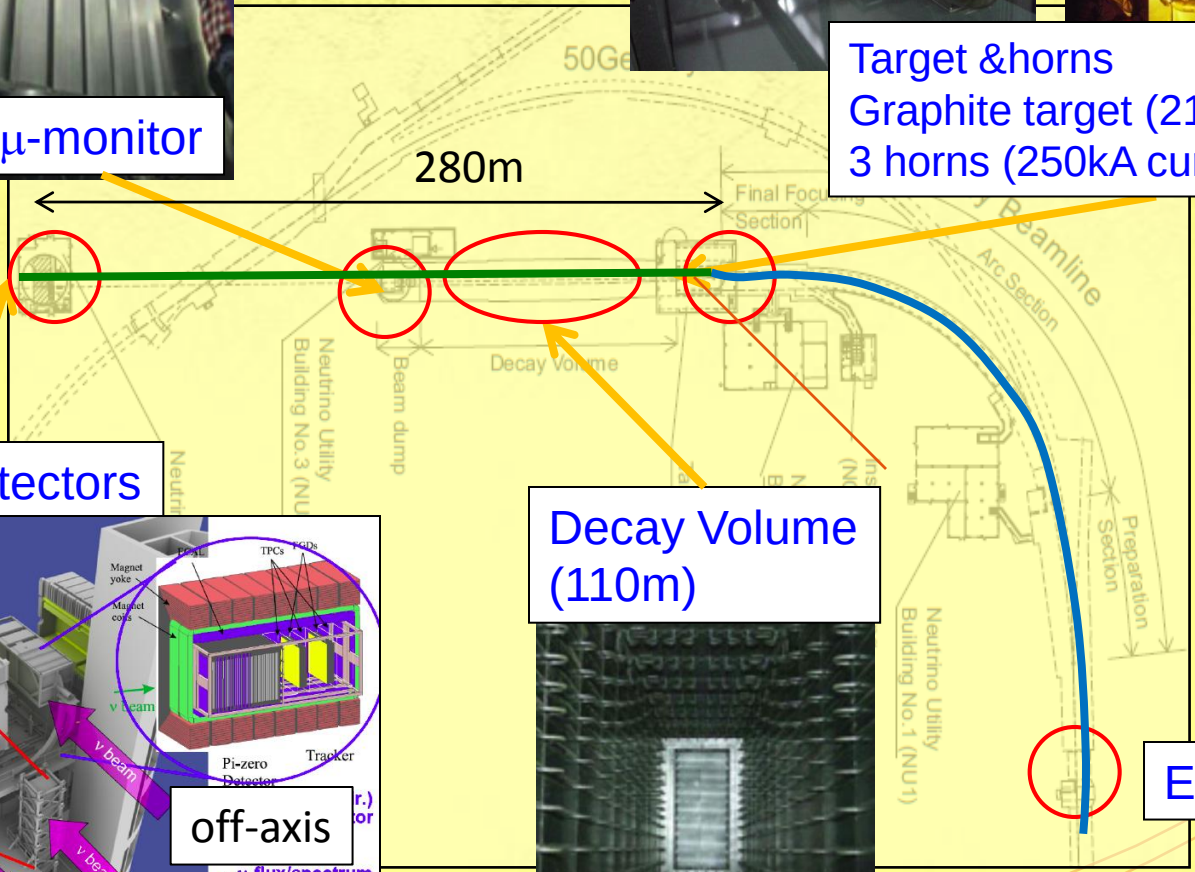
Neutrino Beam line



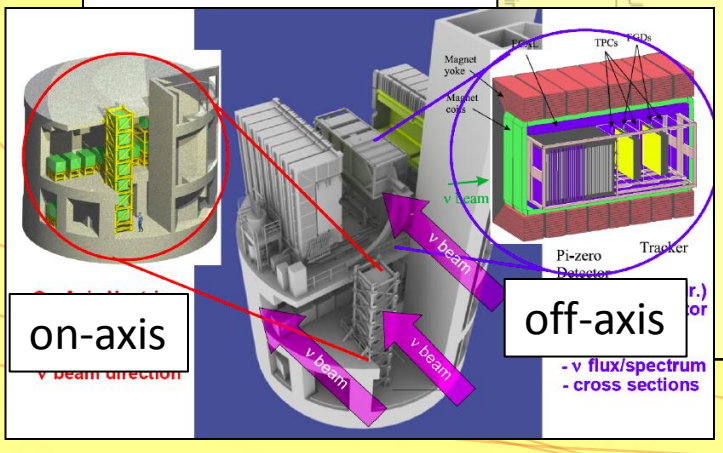
μ-monitor

280m

Target &horns
Graphite target (21mmϕ, 90mm)
3 horns (250kA currently)



ν Near Detectors



on-axis

off-axis

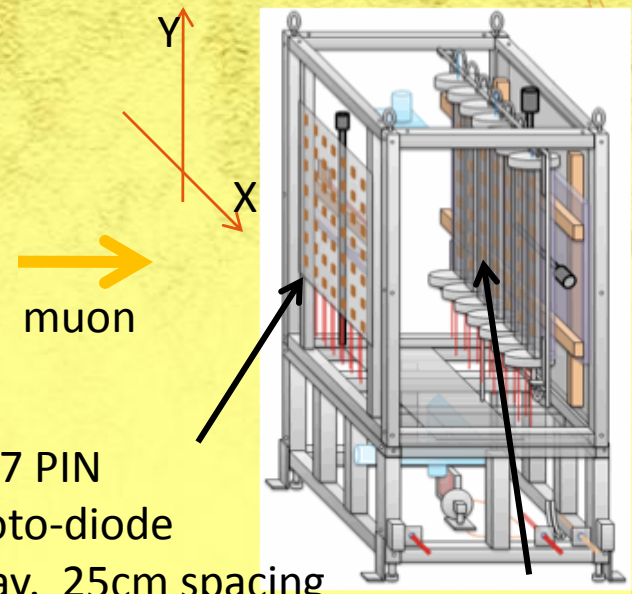
Decay Volume (110m)

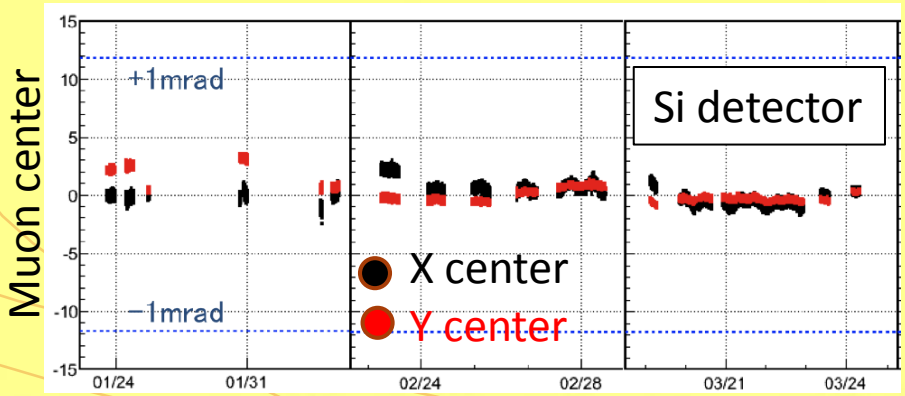
Extraction point

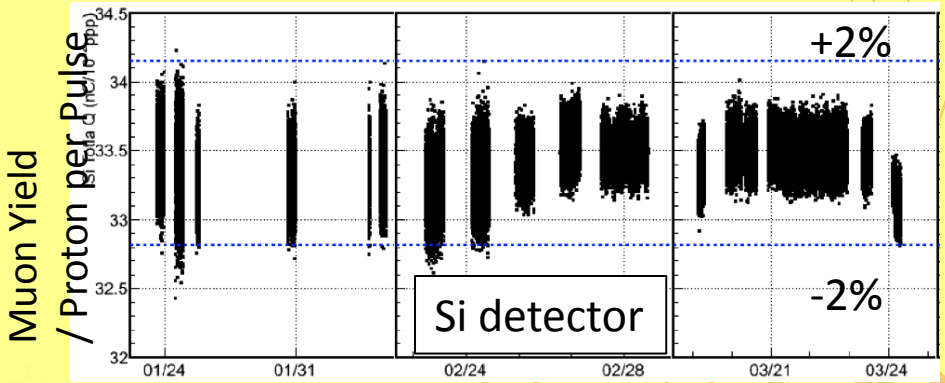
Bird's eye photo in July. 2009

Beam direction / intensity stability using Muon Monitors

- Located downstream of beam dump.
- Monitoring muons from pion decay ($\pi \rightarrow \nu + \mu$) with a threshold of $P\mu > 5GeV/c$.
- Monitoring spill-by-spill.
- Physics requirement: control beam direction < 1mrad.



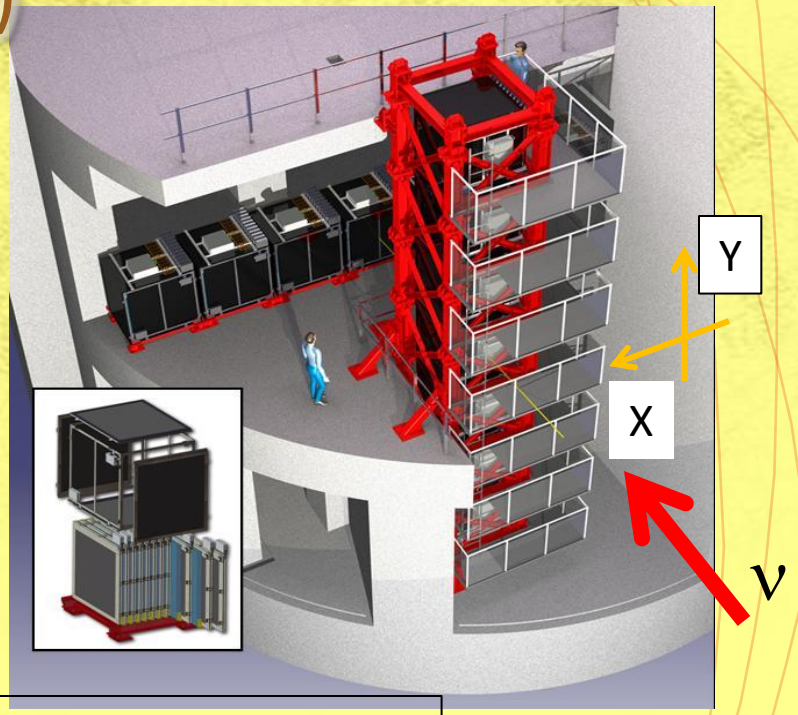


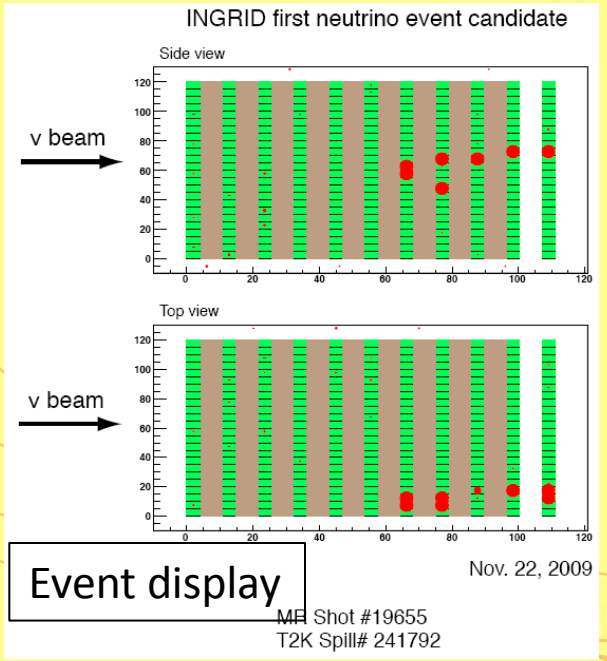


Beam is well controlled, stable.

On-Axis Near Detector (INGRID)

- Daily measurement of neutrino beam direction with <1mrad accuracy.
- 7modules in horizontal, 7 modules in vertical.
- A module is calorimeter of Scintillator tracking plane /Iron plane.

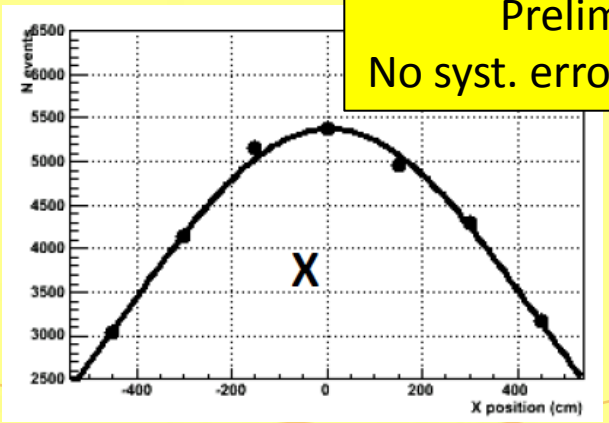




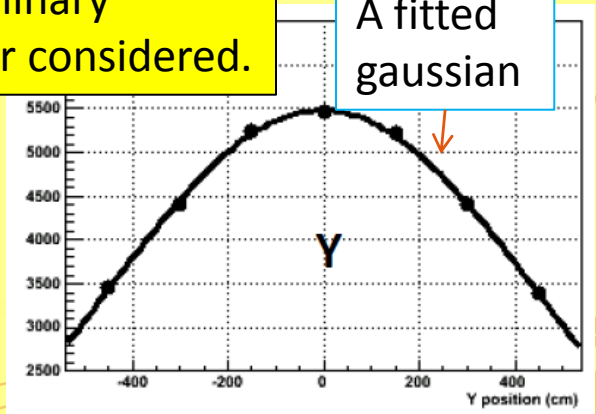
Event display

Neutrino Beam Profile

Preliminary
No syst. error considered.

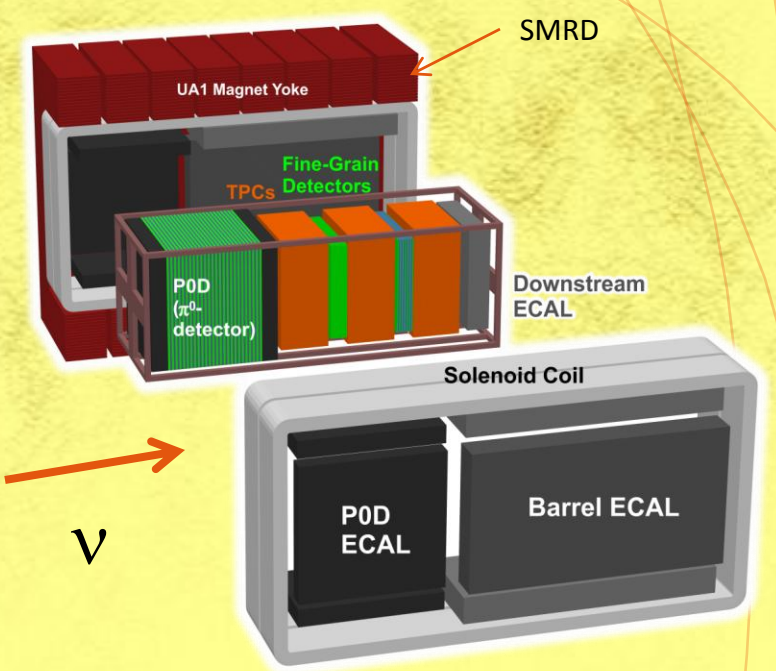


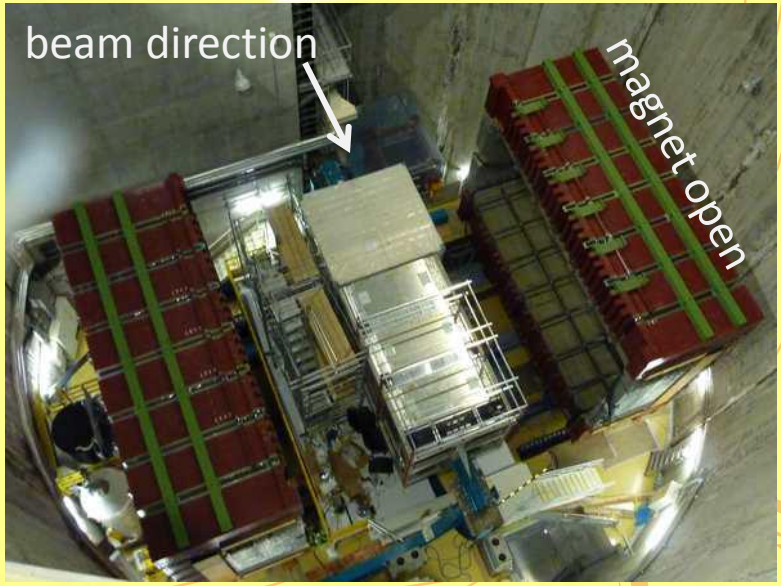
A fitted gaussian



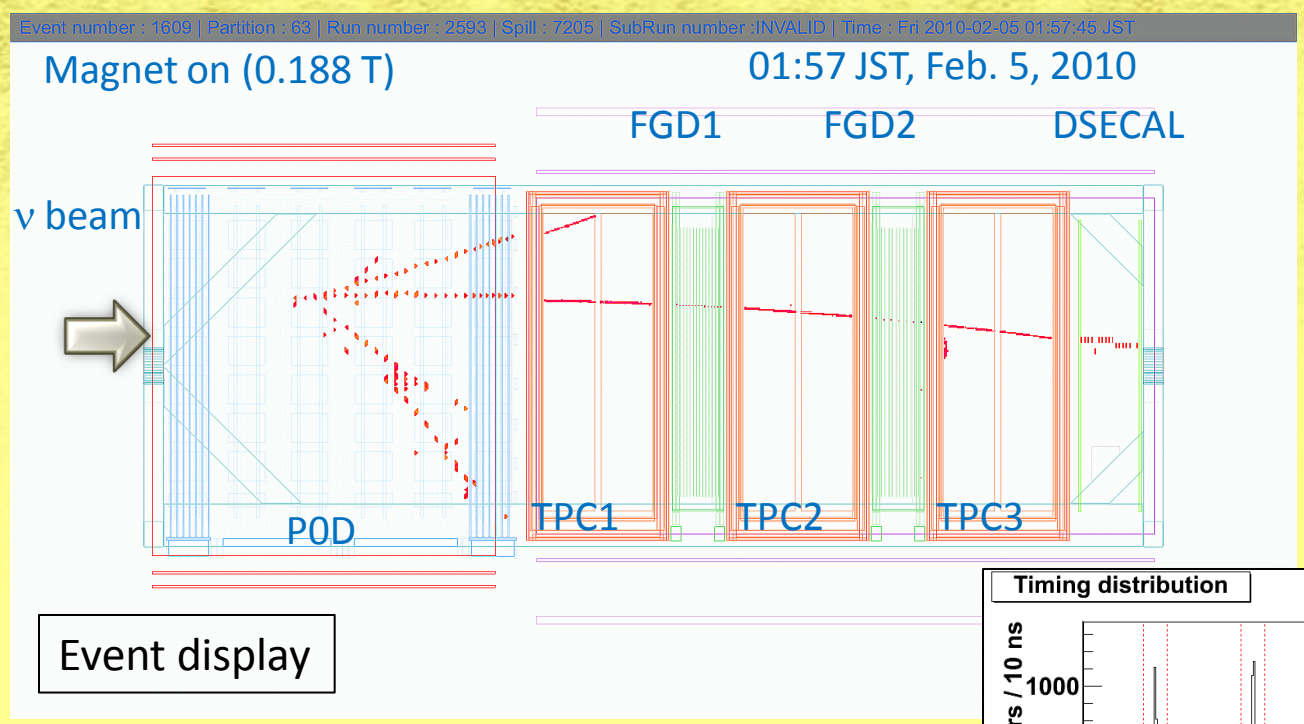
Off-Axis Detector

- Measure neutrino flux and cross section
- UA1 Magnet 0.2 T field
- Tracker Region: Fine Grained Detectors (FGDs) & TPCs
  - Particle Tracking (p,θ) & identification
- P0D
  - Measure NC π^0 rate
- Includes a water target in P0D and FGD2
  - Understand interactions on H_20 target
- ECAL (Downtream Currently Installed)
  - Surrounds tracker and P0D
  - Capture EM energy
  - Rest of ECAL is to be installed this summer
- SMRD
  - Muon ranging instrumentation in the magnet yoke



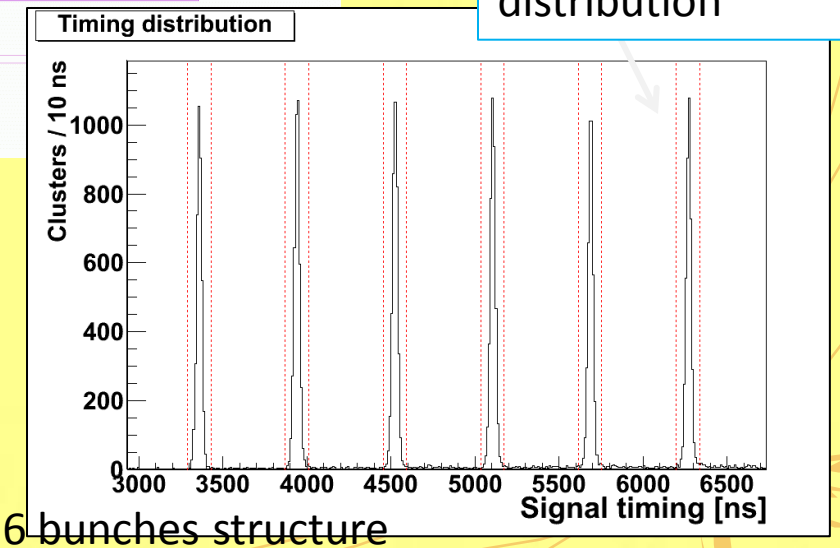


Off-Axis Detector



Event display

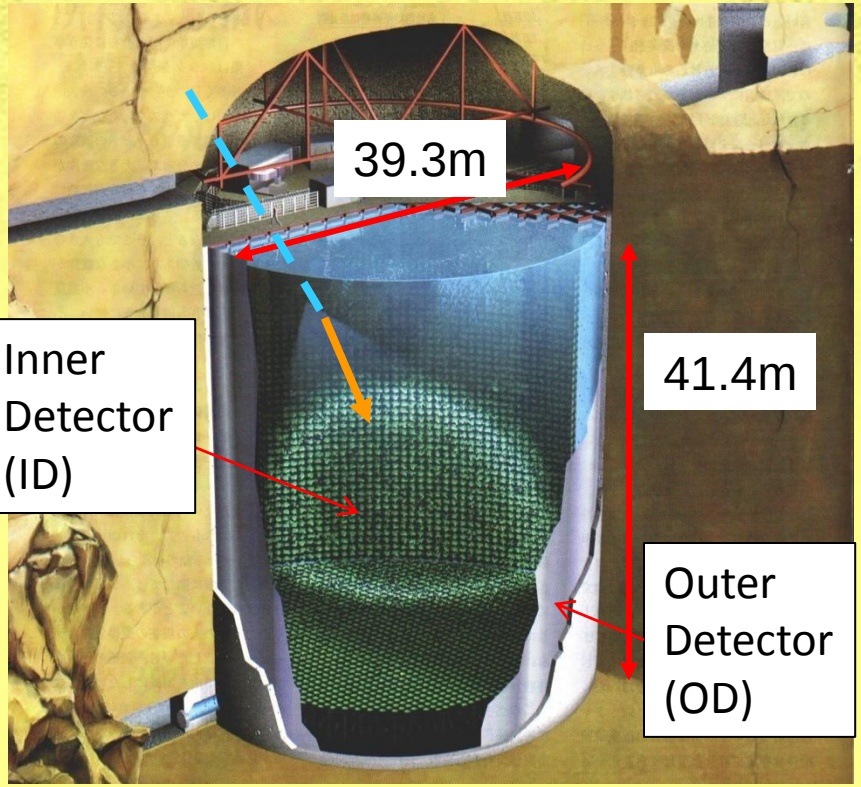
FGD Signal timing distribution



Off axis detector successfully started Physics data taking.
Detectors running stably.

6 bunches structure of the beam spill is clearly seen.

Far detector: Super-Kamiokande IV



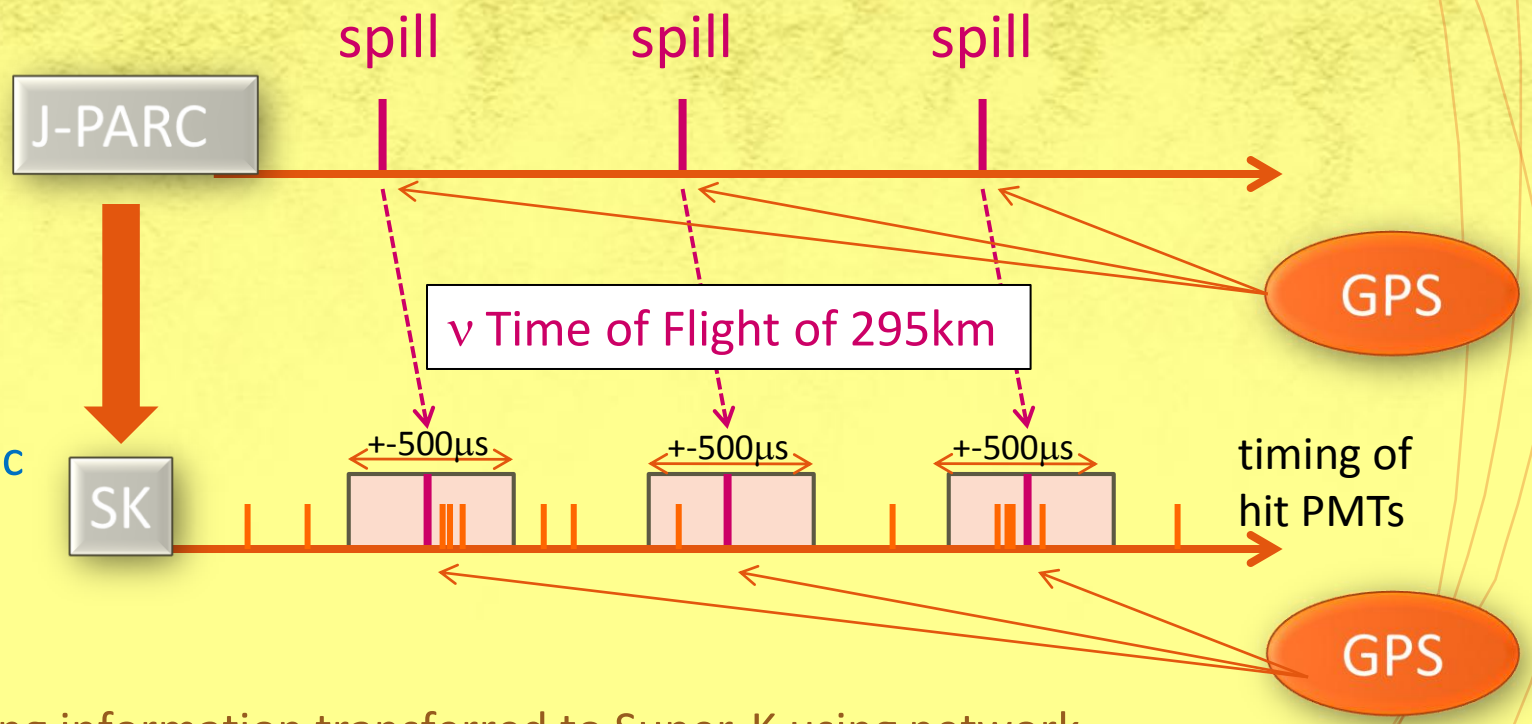
- Water Cherenkov detector
- Deep underground (1000m, 2700 m.w.e), Kamioka-mine, Japan.
- Cylindrical shape,50kton water (22.5 kton fid.vol)
- Optically separated Inner Detector/ Outer Detector
- ID : 11129 20inch PMTs (~40% photo-coverage)
- OD: 1885 8inch PMTs
- SK-IV started Aug.2008 with new frontend electronics.

- 4π acceptance, very efficient π^0/e separation.
- High Particle ID (μ/e) power (~99% at 600MeV/c)
- Good energy reconstruction.
- Methods are established.

T2K data acquisition at Super-Kamiokande

T2K events are acquired by GPS timing information of beam

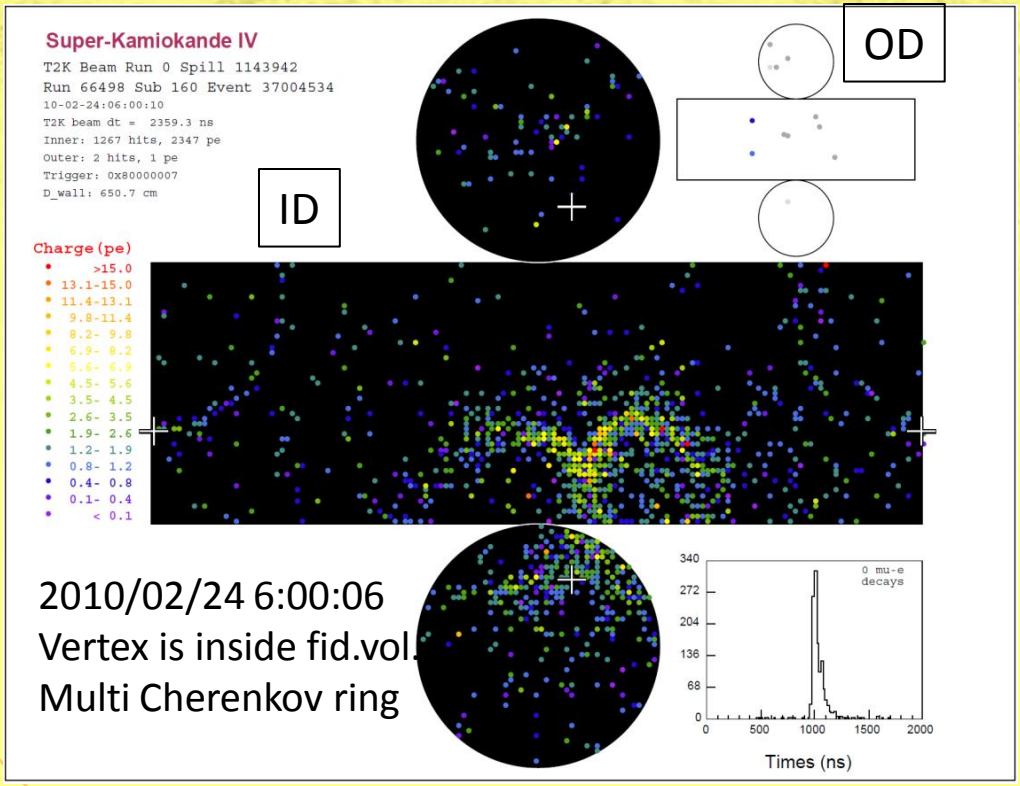
GPS timing information of every spill are transferred to SK within ~1sec



- GPS timing information transferred to Super-K using network.
- All the PMT hits in +-500μsec from spill timing at SK are recorded as "T2K triggered" event.
- Low energy activity induced by neutrino interaction can be acquired. (ex. de-excitation γ's from nuclei induced by NC elastic scattering)

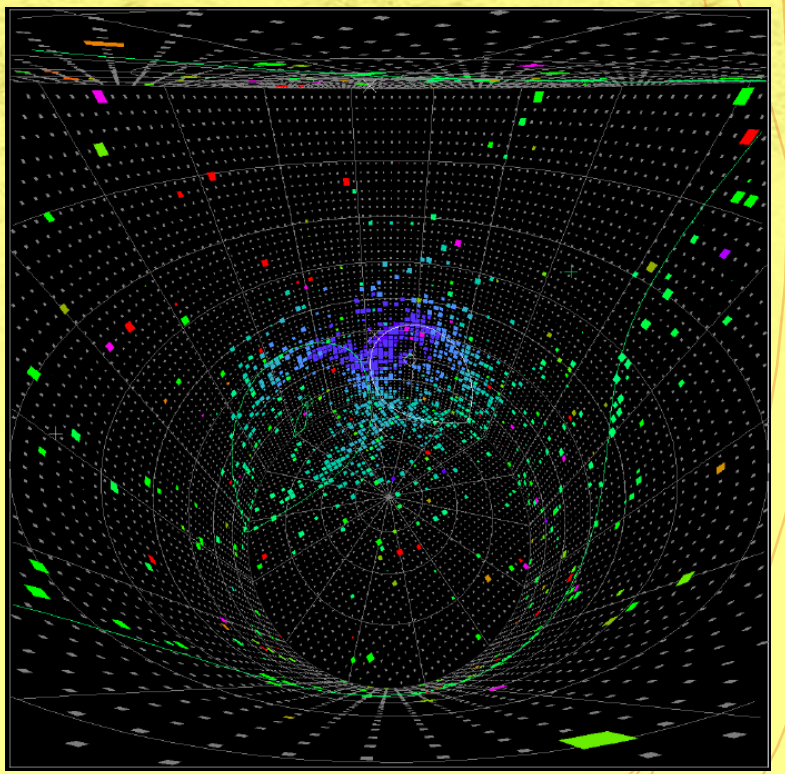
First T2K beam ν Event at Super-Kamiokande

Event display



2010/02/24 6:00:06
Vertex is inside fid.vol.
Multi Cherenkov ring

3D view



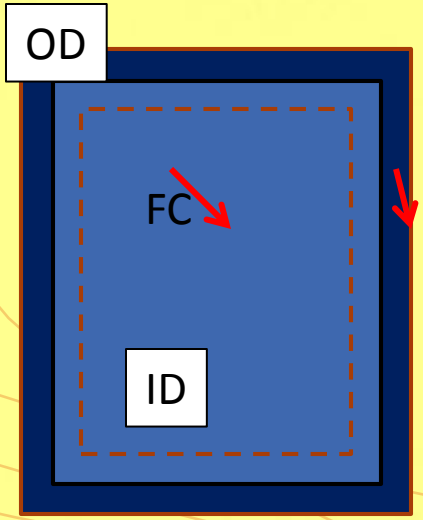
2 Fully Contained (all visible particle inside ID) events are observed.(by end of March). Expected B.G. from atm.ν~1.9×10^{-4}

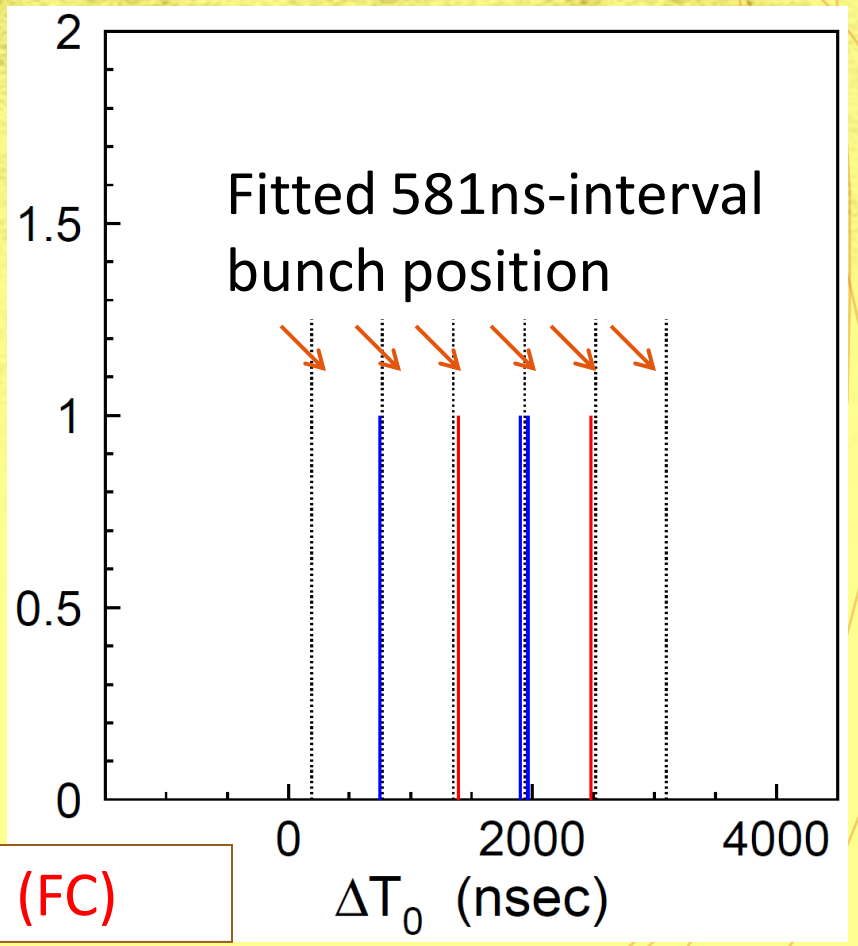
Timing distribution of Super-Kamiokande events

ΔT_0 = SK event time (GPS)
– SK hardware offset (972nsec)
– TOF (295km)
– Spill time at Tokai(GPS)

Also,
- Neutrino flight length in SK
- Photon travel length difference

are corrected.



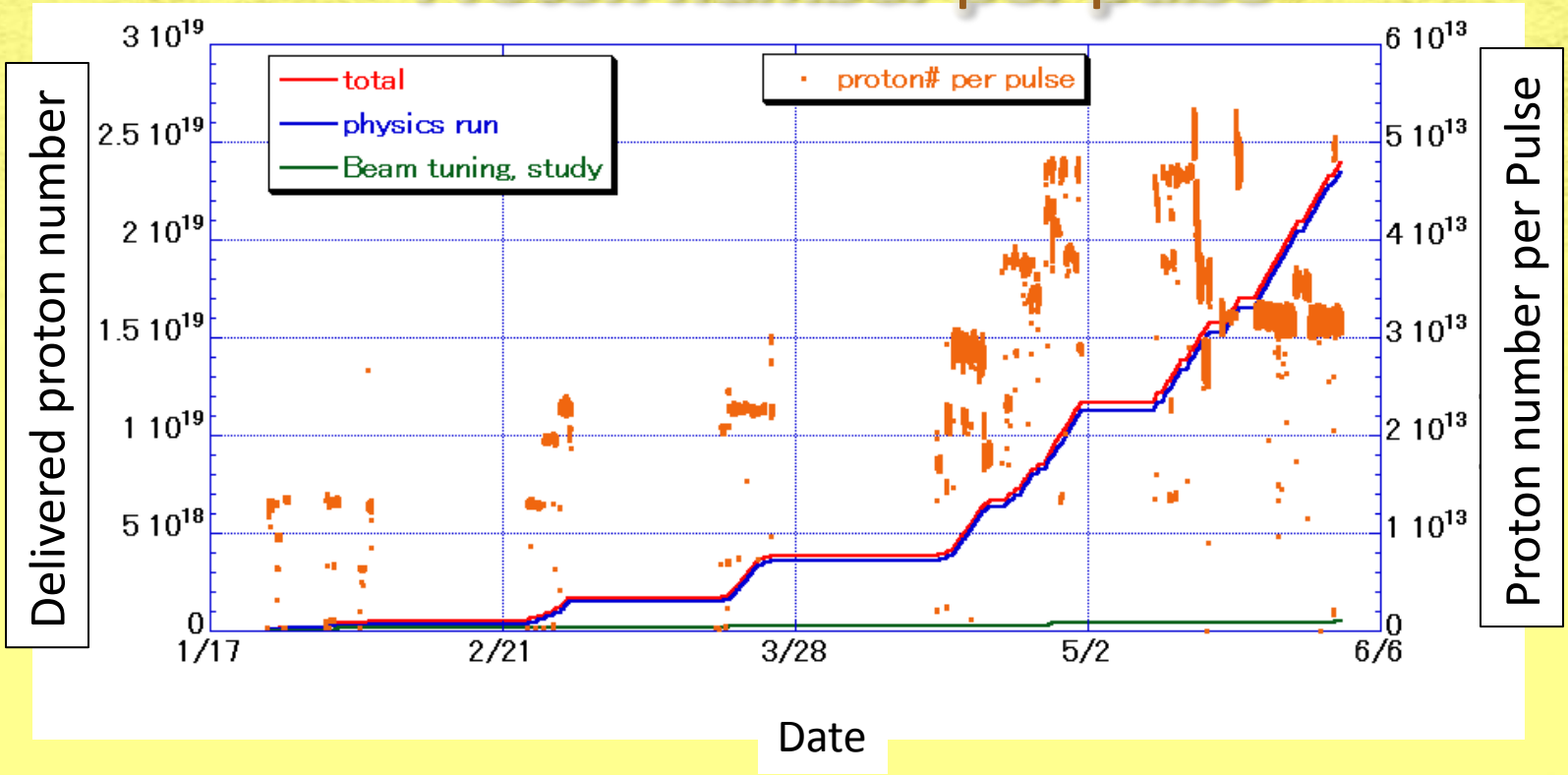


Red: Fully Contained (FC)

Blue: Only OD activity events (ODC)

Spill structure is clearly visible at Super-K !

Delivered Proton number, Proton number per pulse



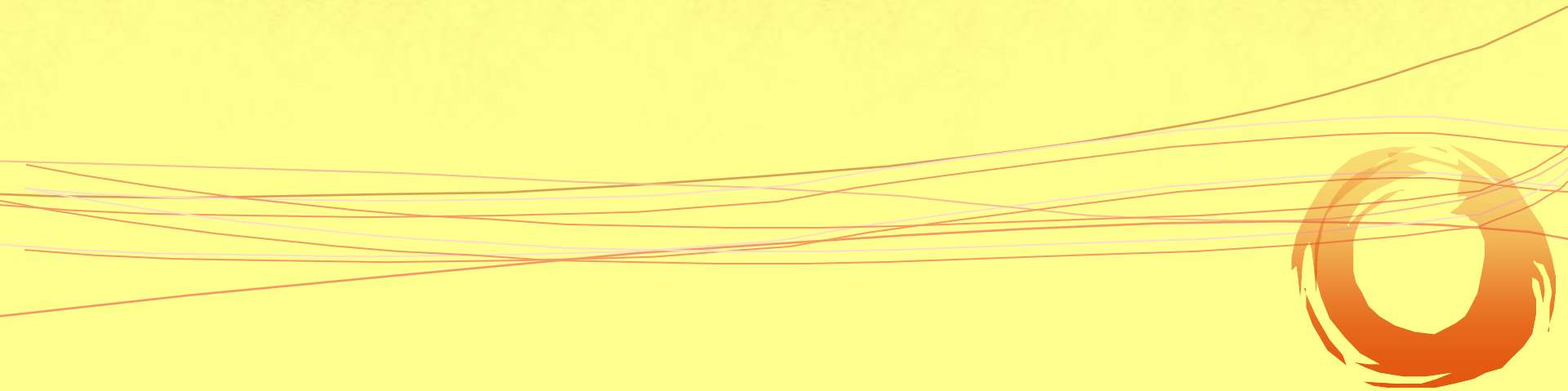
T2K experiment has been stably running.

~ 2.4x10^{19} Protons are delivered by beginning of June 2010.

Summary

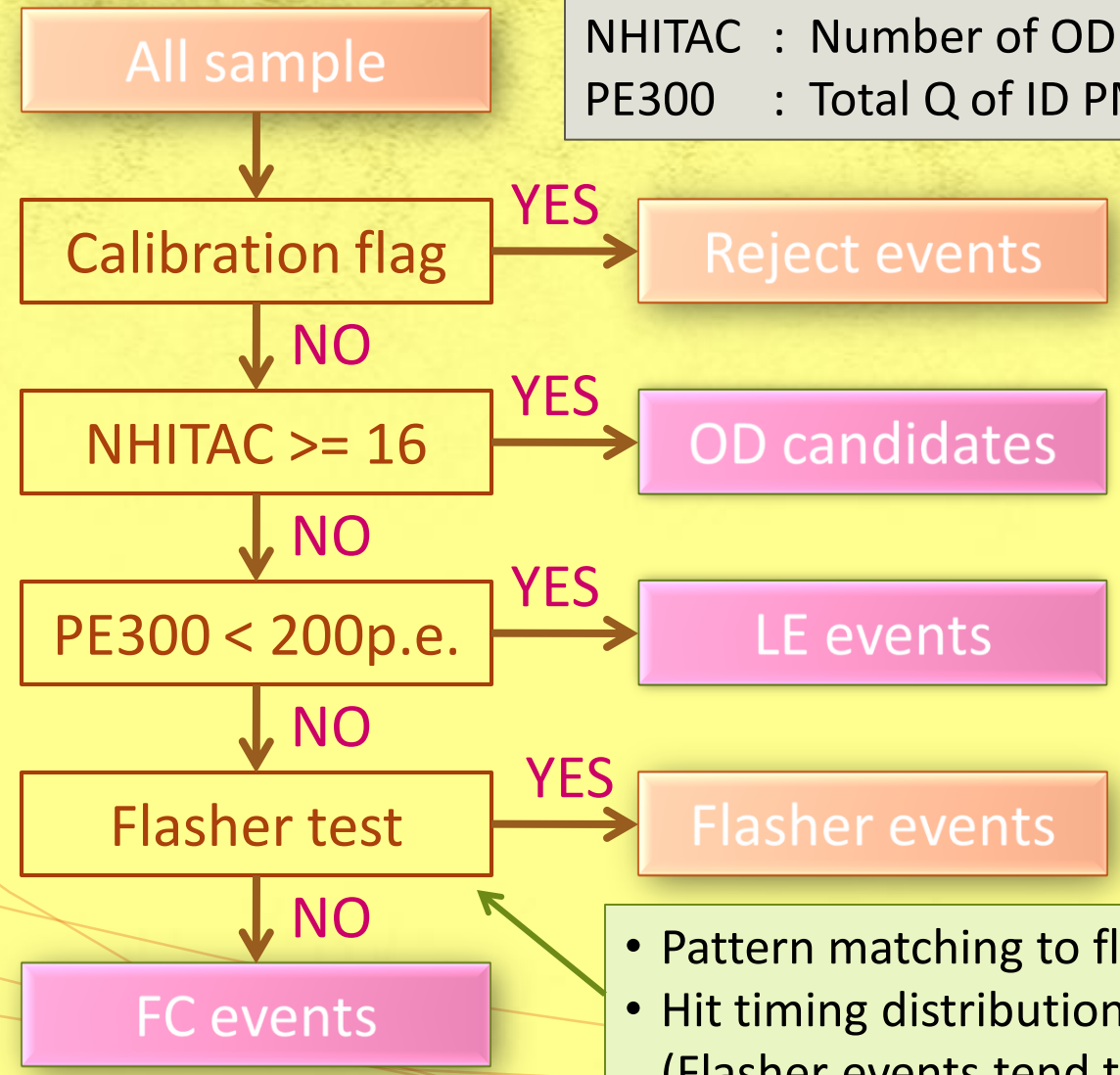
- T2K is the first LBL neutrino oscillation experiment with off-axis beam.
- Started $\nu_\mu \rightarrow \nu_e$ neutrino oscillation search from Jan. 2010 !
- Super-K observed first T2K beam event in Feb.2010.
  (2 of FC events are observed by end of March.)
- Stably running. Beam power ~50 kW now.
- After summer beam power is planned to increase over 100kW.
- First physics results expected in 2010.
- Sensitivity to $\sin^2 2\theta_{13}$ ~ 0.06 for 100kWx10^7s (~2x10^{20}POT) data.
- Stay Tuned !

Supplements



Event classification

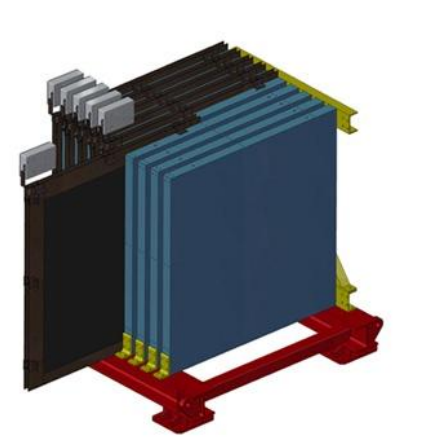
NHITAC : Number of OD PMT hits in a cluster
PE300 : Total Q of ID PMT hits in a 300ns window

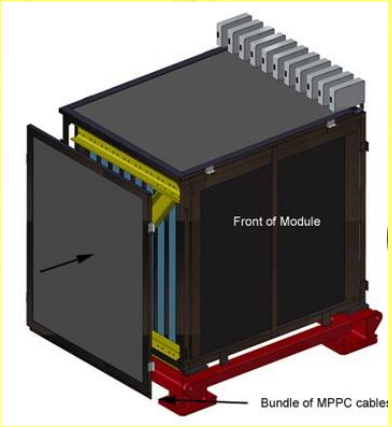


- Pattern matching to flasher event database
- Hit timing distribution
  (Flasher events tend to have a longer tail)

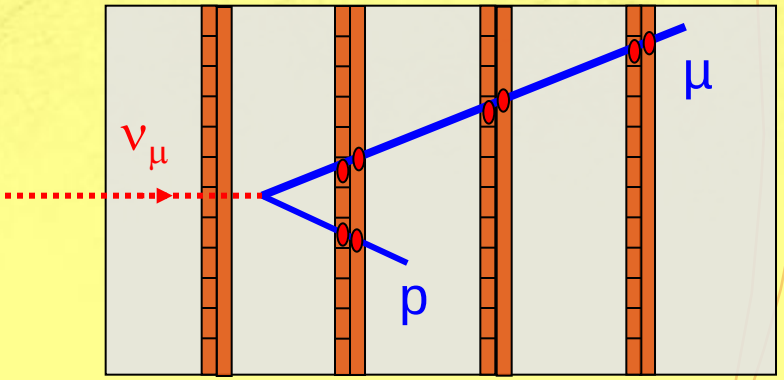
INGRID

- **Module** : Iron target (9 layers) + Tracking plane (11 layers) + Veto plane (3~4 layers)

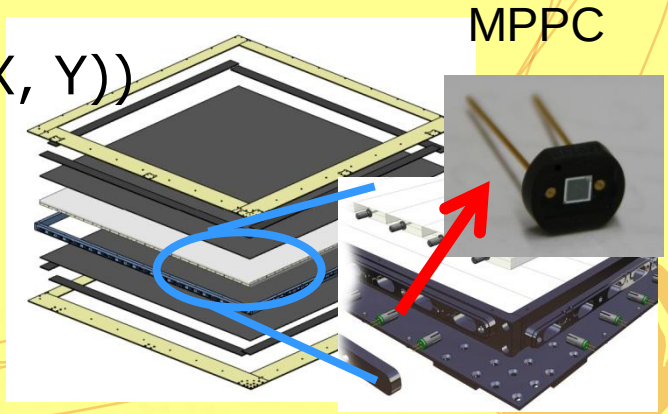




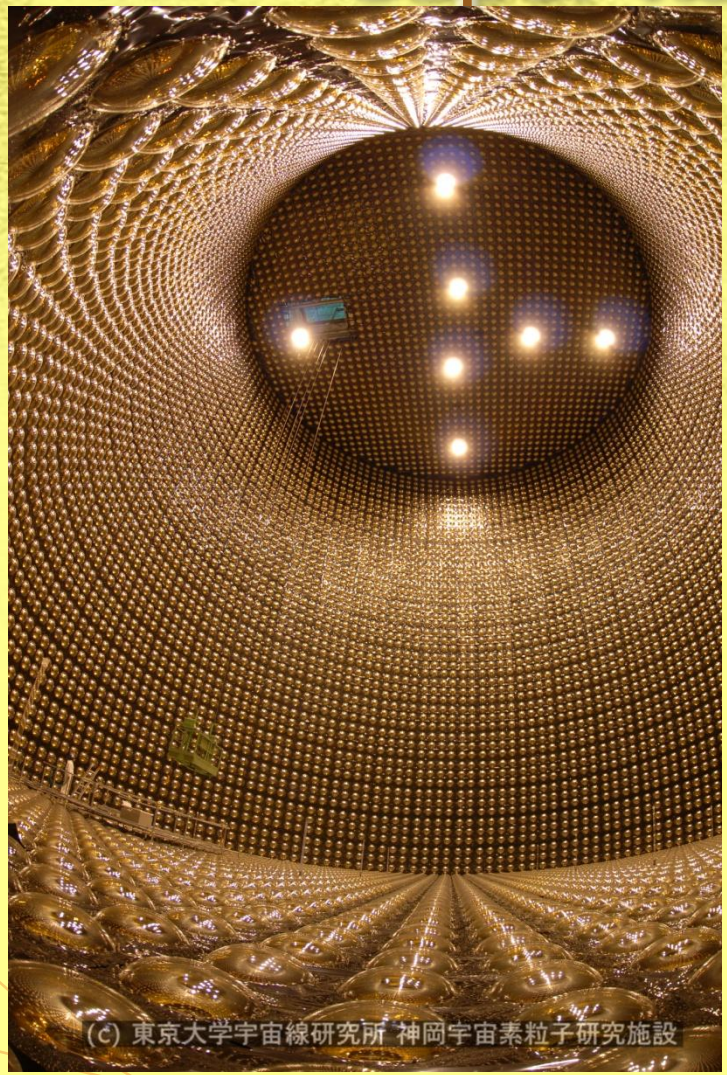
Typical neutrino event

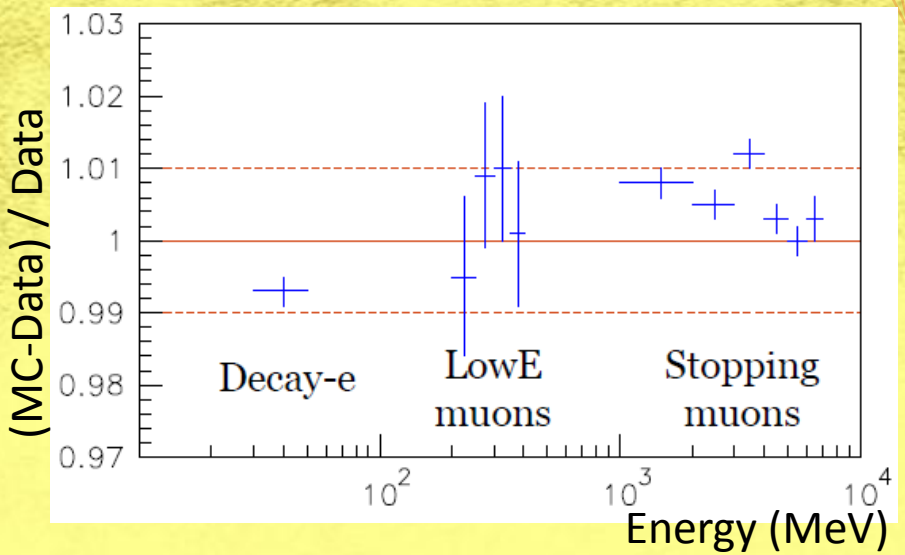


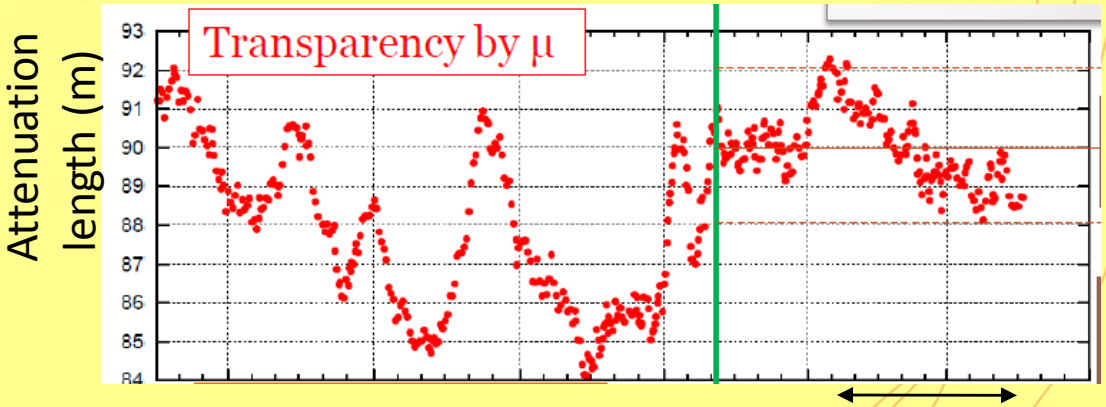
- Tracking plane (24 ch x 2layer (X, Y))
  - Scintillator
  - WLS fiber
  - MPPC (Multi Pixel Photon Counter)



Super-Kamiokande status







1% level energy scale calibration
Stable water quality
No dead time during T2K (~99% including all period)