Status of the T2K experiment

Ken Sakashita(KEK) for the T2K collaboration
2009/July/17, EPS HEP conference

1. Introduction of T2K experiment
   - Motivation, Features and Sensitivity
2. Beam Commissioning in Apr-May '09
   - **T2K ν beam-line operation started**
3. Status of preparation toward physics run
4. Future prospects
5. Summary

Next step of ν oscillation experiment

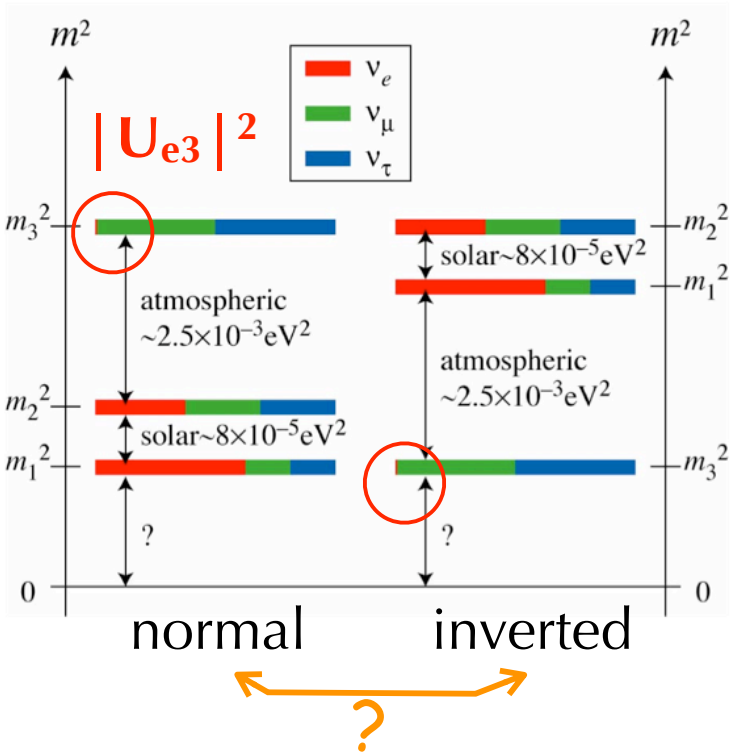
Neutrino Oscillation Experiment

- **discover a finite θ_{13}**
  - determine $|U_{e3}|$
    - → **important role for future neutrino experiments**
      - **CPV in lepton sector**
        - → hint on Baryon# asymmetry of Universe
      - mass hierarchy
- **precise measurement**
  - Is θ_{23} maximal ?

$U_{e3} = s_{13}e^{-i\delta}$

NEUTRINOS

$$U_{MNSP} \sim \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$



0νββ decay exp.
- Dirac or Majorana

Tritium β decay exp.
- absolute mass scale

Next step of ν oscillation experiment

Neutrino Oscillation Experiment

- **discover a finite θ_{13}** — *T2K: ν_e appearance*
  - determine $|U_{e3}|$
    - → **important role for future neutrino experiments**
      - **CPV in lepton sector**
        - → hint on Baryon# asymmetry of Universe
      - mass hierarchy
- **precise measurement** — *T2K: ν_μ disappearance*
  - Is θ_{23} maximal ?

$U_{e3} = s_{13}e^{-i\delta}$

NEUTRINOS

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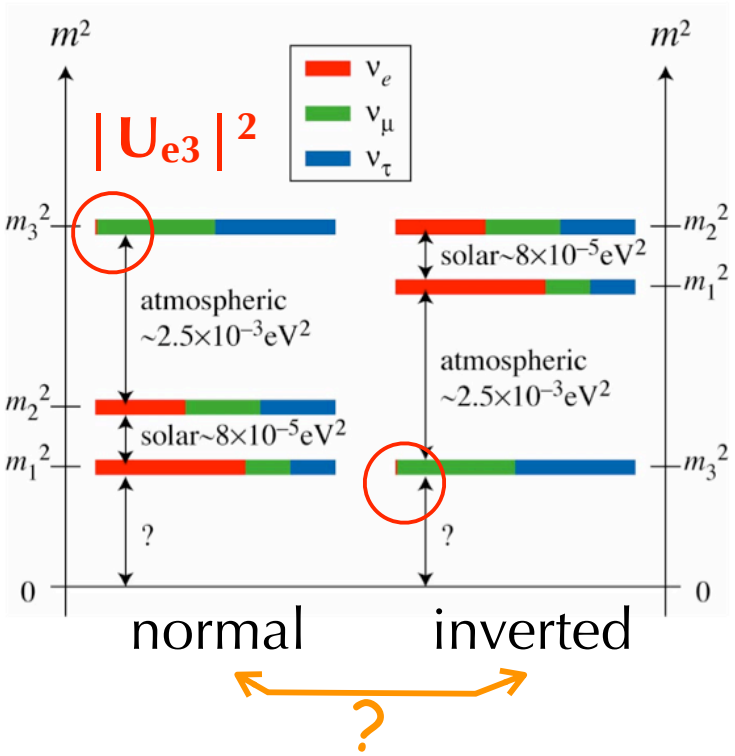


0νββ decay exp.

- Dirac or Majorana

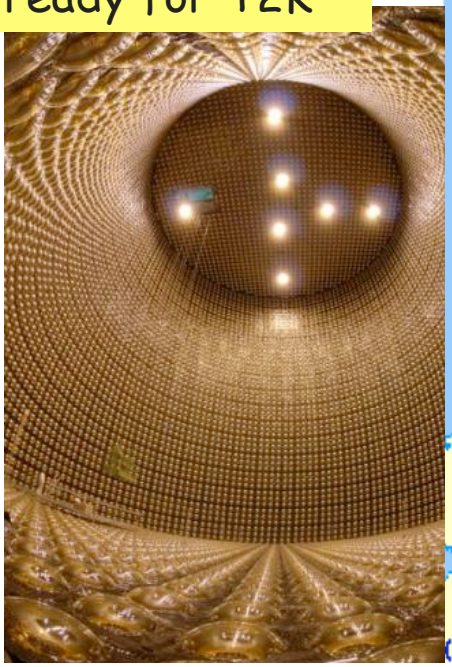
Tritium β decay exp.

- absolute mass scale

T2K Experiment

Long base-line ν oscillation experiment in Japan

Supre-K
ready for T2K



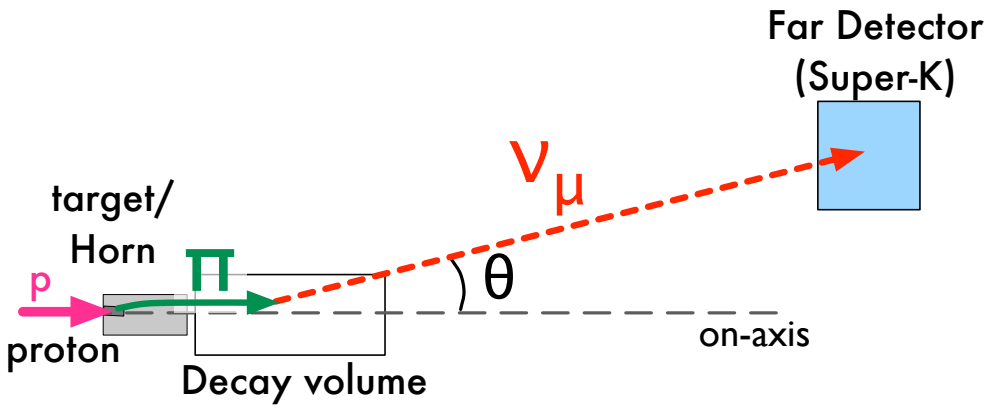
New accelerator(~MW),
ν beam-line & detector

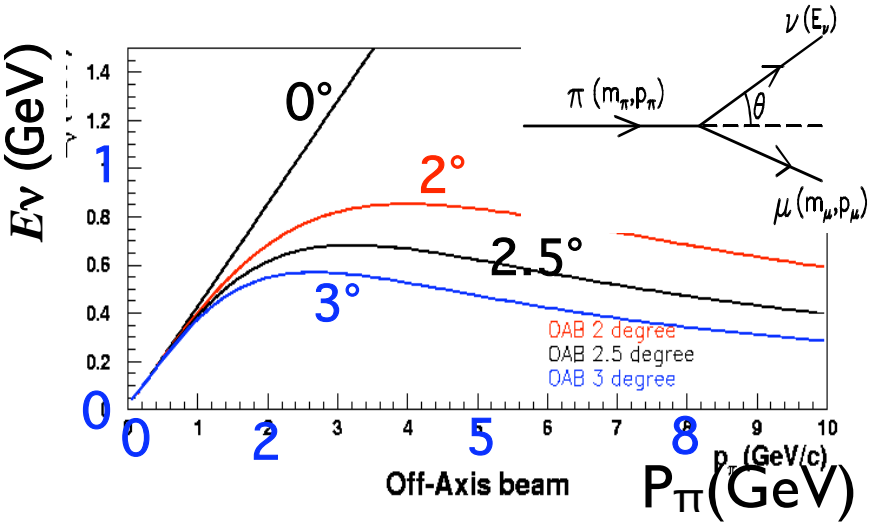
T2K first beam commissioning
in Apr-May '09

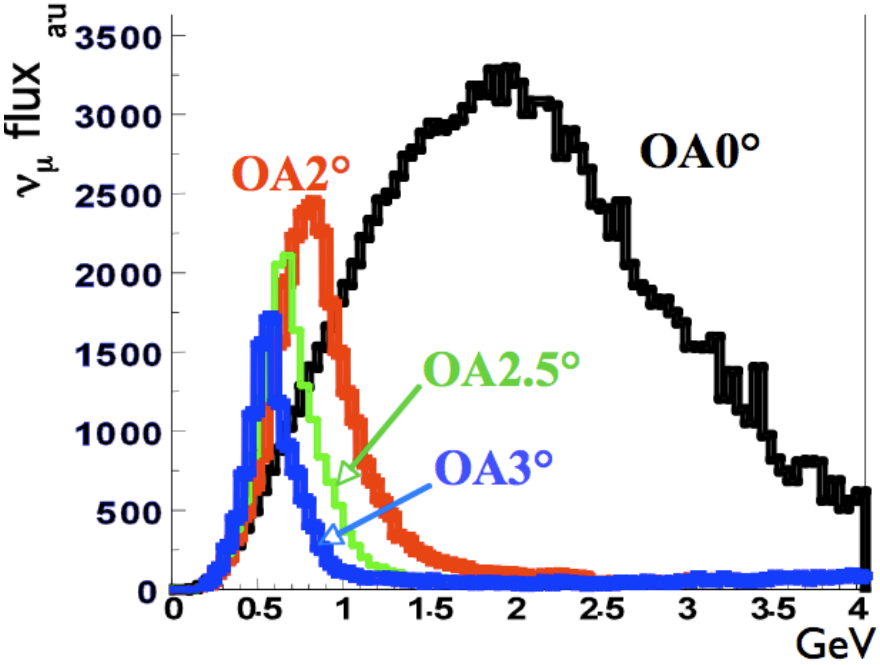
T2K features to enhance the sensitivity

- **Super-K(SK) as main neutrino detector** :
  22.5kton(fiducial) water cherenkov detector & good PID (e/μ) performance
- **Off-axis beam** (intense & narrow-band low energy neutrino beam) ⟶ next slide
- **Neutrino energy reconstruction** :
  CCQE interactions dominate at T2K beam energy

Off-axis beam : intense & narrow-band beam







the beam energy depends on the off-axis angle (beam direction)

set off-axis angle to 2.5°

→ beam energy at oscillation max.

(current Δm^2_{23} & L=295km)

- ~1.2k CC int./year for SK
- small high E_ν tail (narrow-band)

→ **small # of bkg. for CCQE**

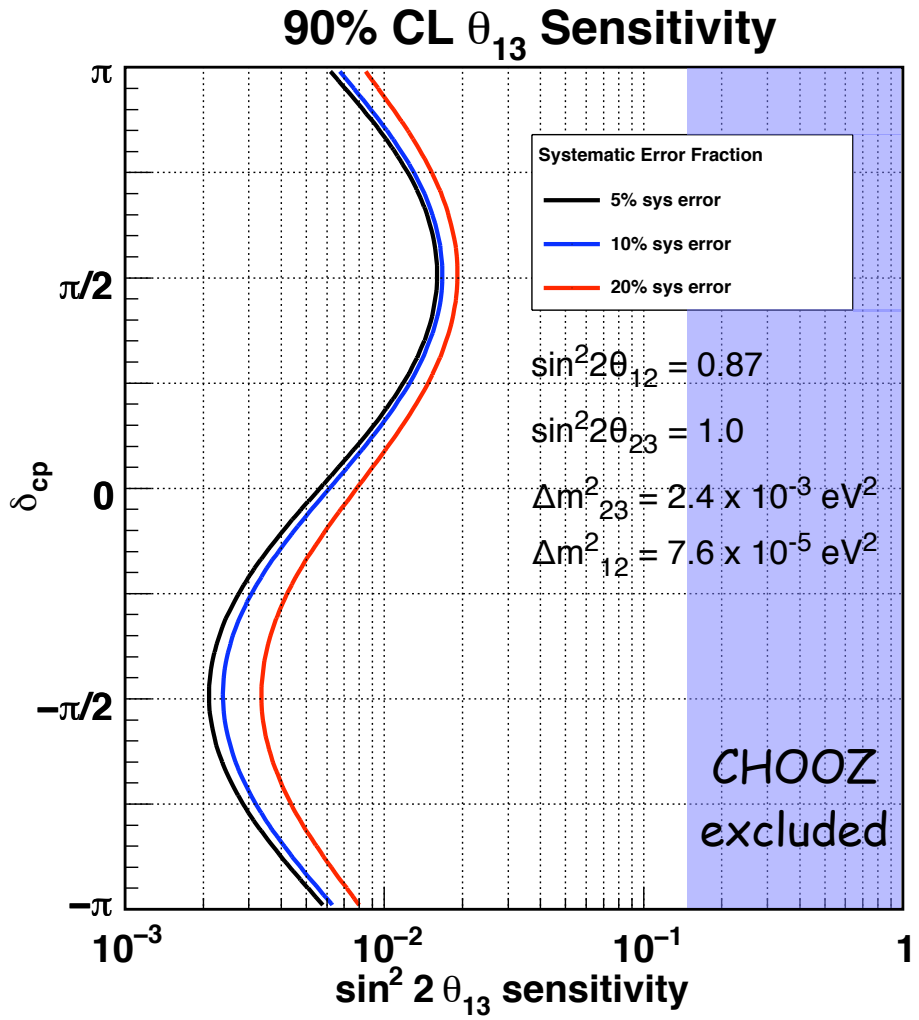
Important to keep the beam direction stable

(monitoring & controlling the beam)

Sensitivity

ν_e appearance

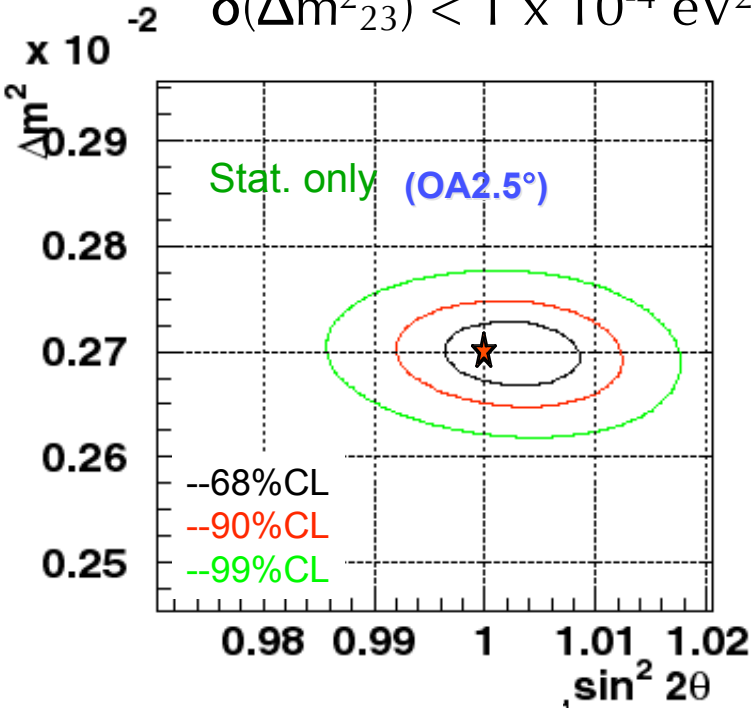
> x10 improvement from CHOOZ limit



ν_μ disappearance

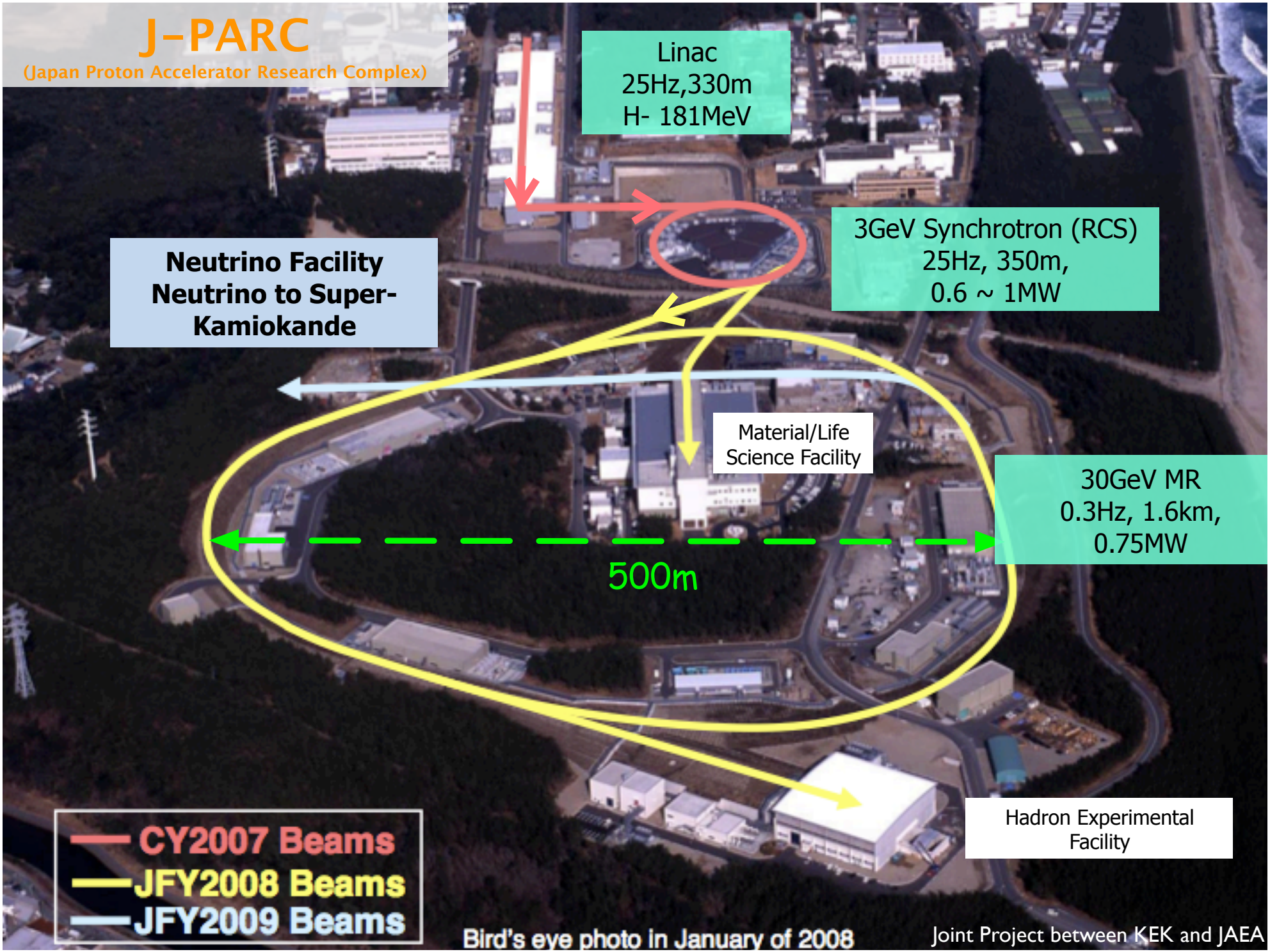
$\delta(\sin^2 2\theta_{23}) \sim 1\%$

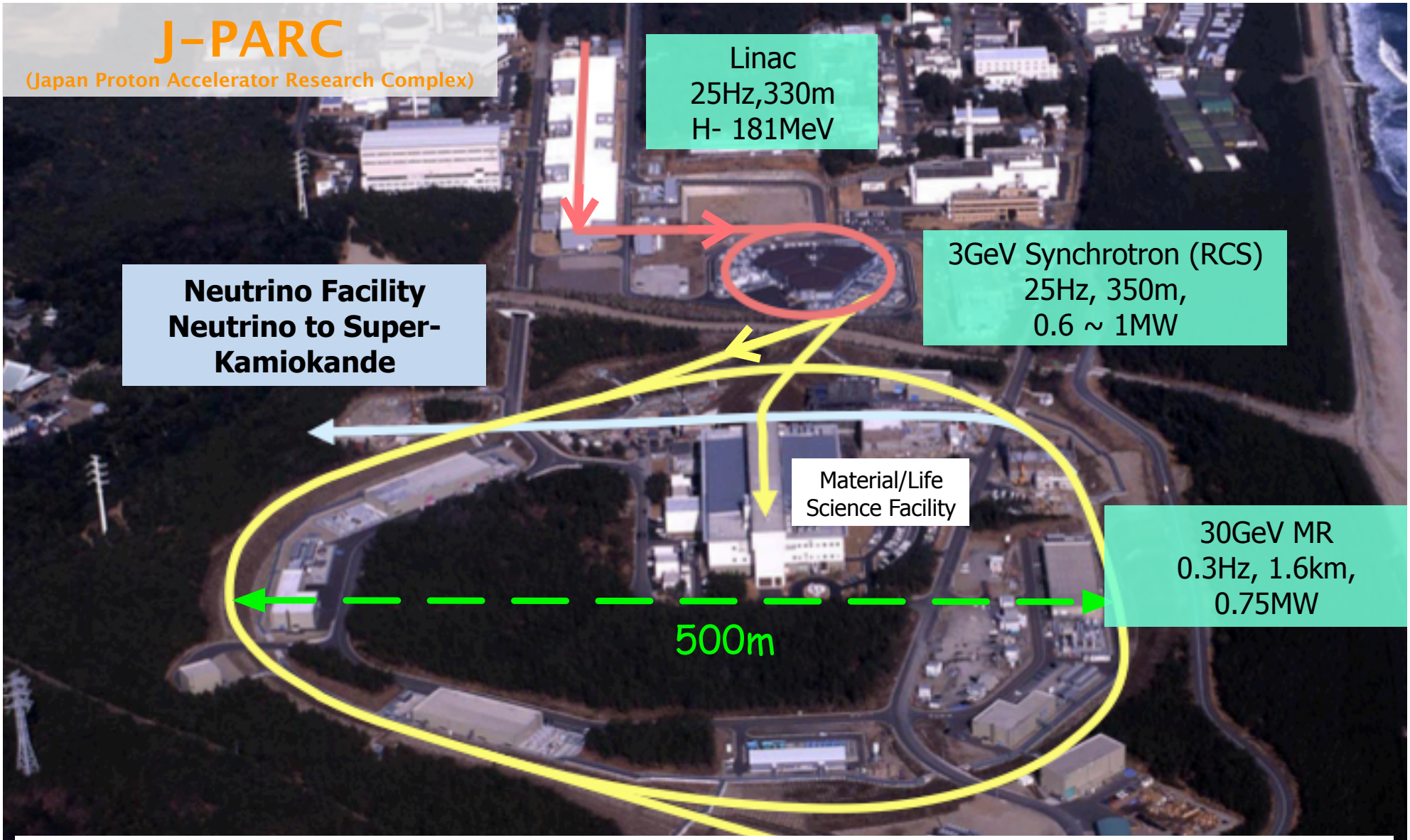
$\delta(\Delta m^2_{23}) < 1 \times 10^{-4}$ eV^2



@ 8×10^{21} protons(30GeV) on target

Beam commissioning
and
status of preparation toward physics run


J-PARC
(Japan Proton Accelerator Research Complex)
Linac
25Hz,330m
H- 181MeV
3GeV Synchrotron (RCS)
25Hz, 350m,
0.6 ~ 1MW
Neutrino Facility
Neutrino to Super-
Kamiokande
Material/Life
Science Facility
30GeV MR
0.3Hz, 1.6km,
0.75MW
500m
Hadron Experimental
Facility
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008
Joint Project between KEK and JAEA

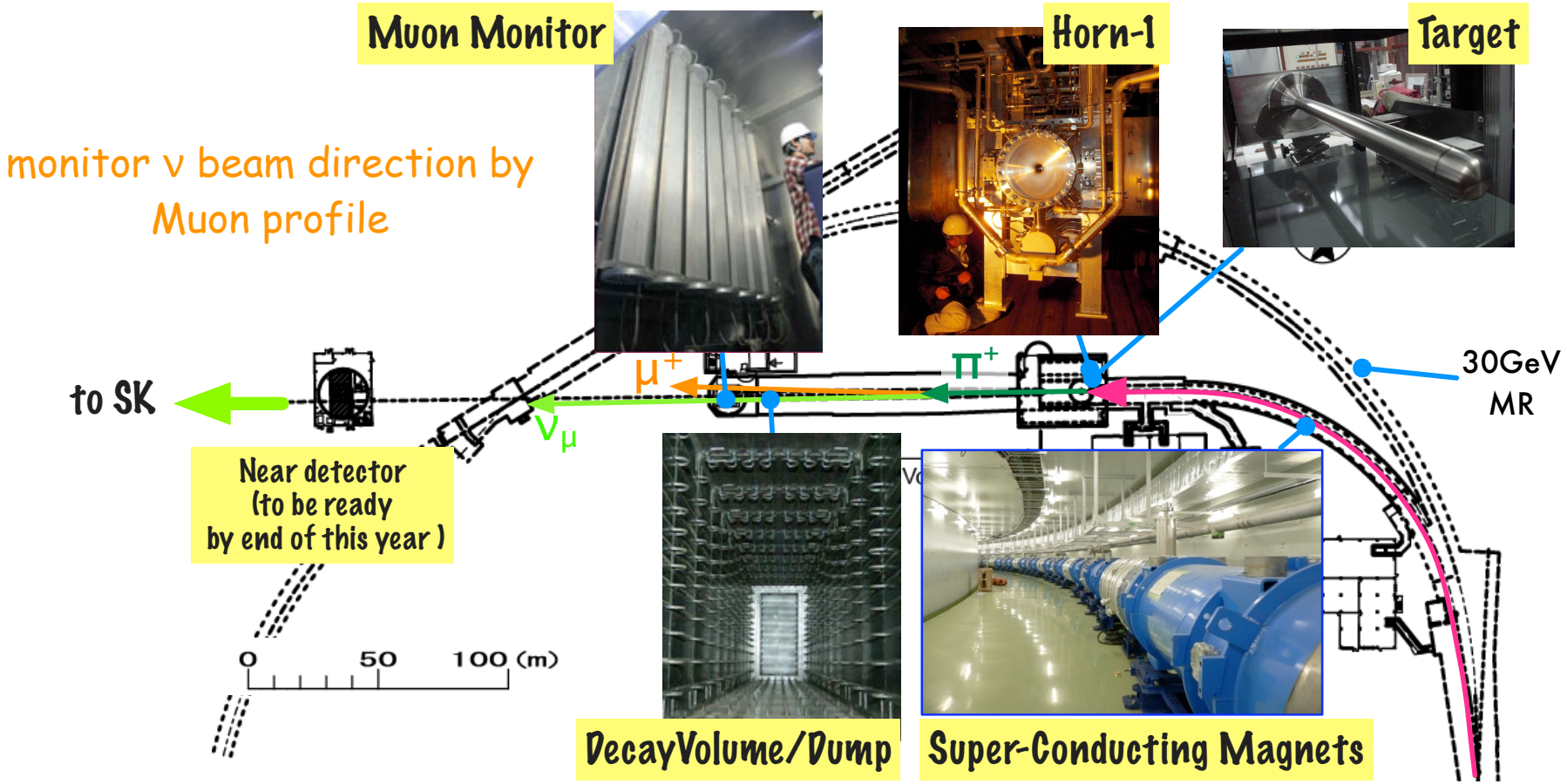


Construction completed & Operation was started

* MR
  - successfully accelerate the beam up to 30GeV (Dec.2008)
  - successfully operate with 6-bunches (so far 3.5kW beam power) (Jun.2009)

T2K Neutrino Beam-line

- Completed the beam-line construction [2004~2009, 5 years]
  (Horn-2,3 to be installed in this summer)



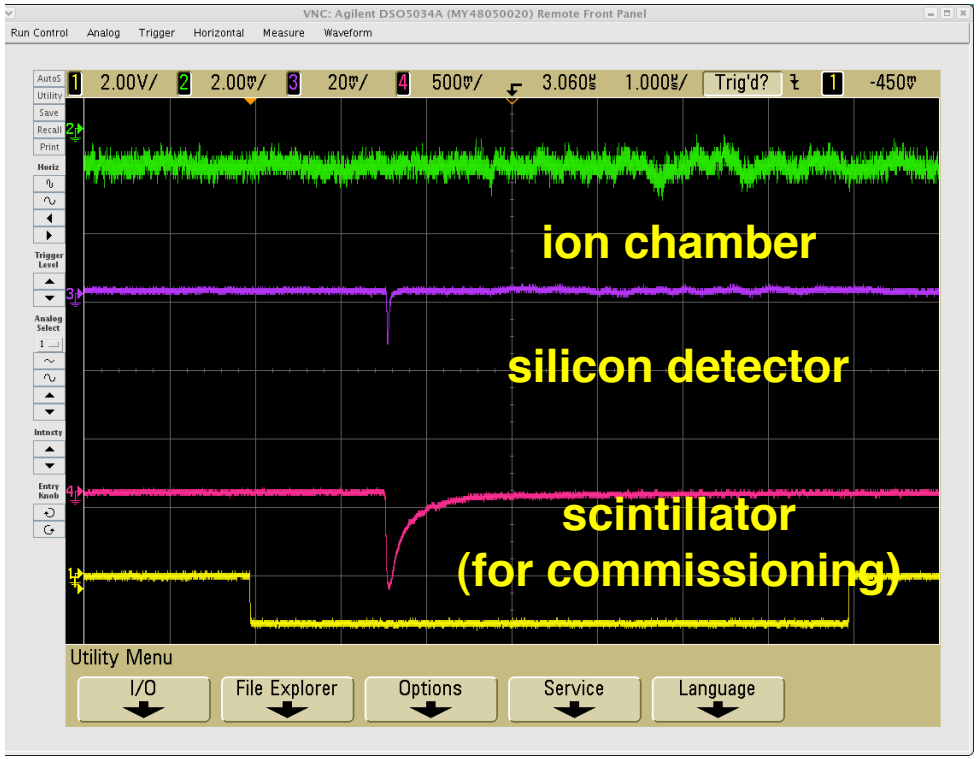
start beam commissioning in April '09 as scheduled

with low intensity (typically 4 x 10^{11} p/pulse) beam to reduce
radio-activation of target area for Horn-2,3 installation in summer '09

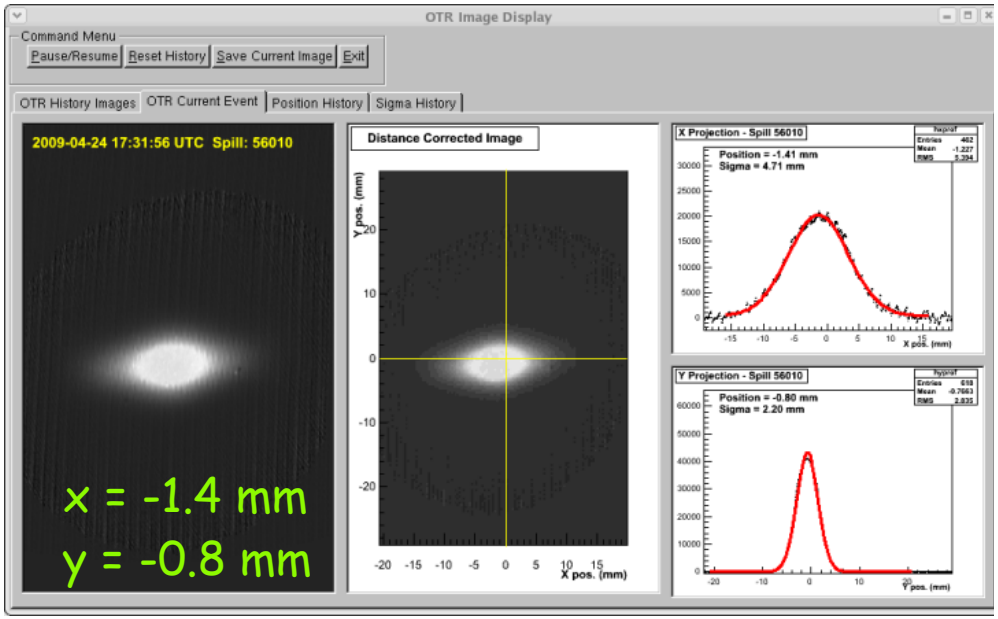
T2K neutrino beam-line starts operation

(First beam in Apr/23/2009)

Muon monitor signal
at 1st shot after SC turned on



proton profile just in front of the target
after 9 shots beam tuning
(fluorescence plate)



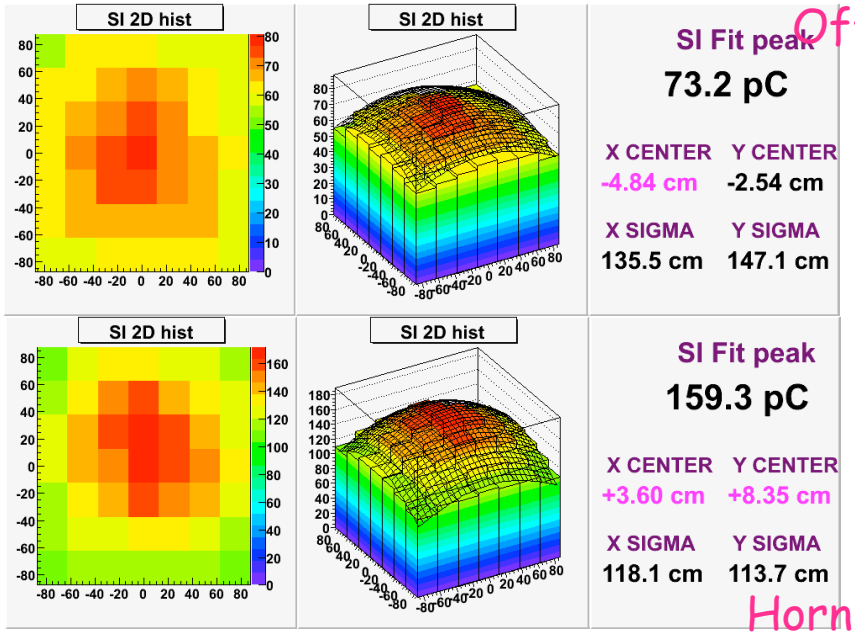
We successfully started to produce neutrino beam

Achievements in the beam commissioning

9 days, 705 shots in total (Apr-May '09)

- ☑ transfer the proton beam without any significant beam loss
- ☑ SC combined function magnets work as expected
- ☑ Muon yield is increased by Horn On
- ☑ control beam position on the target
- ☑ beam dir. was stable ($\Delta\theta_\mu < 1$mrad) during 0.5 hour operation

Muon monitor signal
with/without Horn Magnet (online monitor)

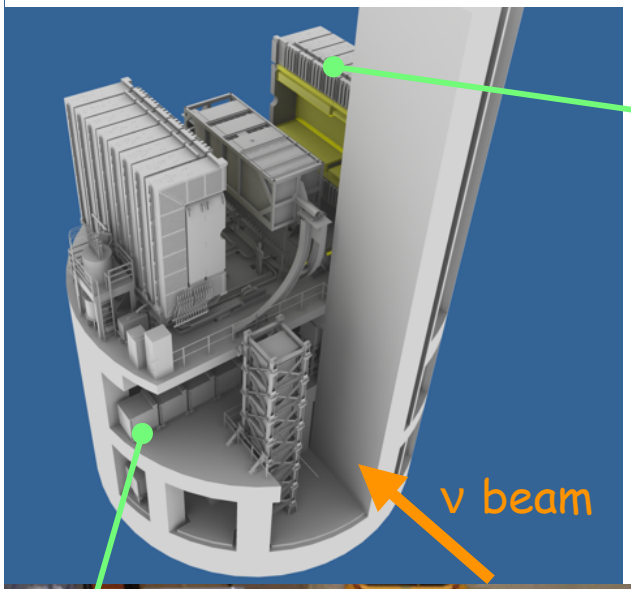


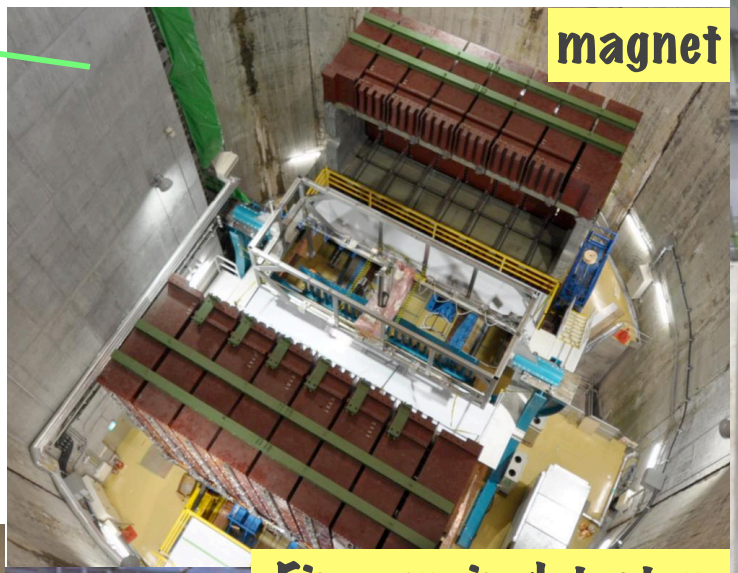
- ☑ Successfully pass the government inspection of radiation
- ☑ operate with several beam condition (e.g. 2-bunches operation)

T2K ν beam-line works with expected performance

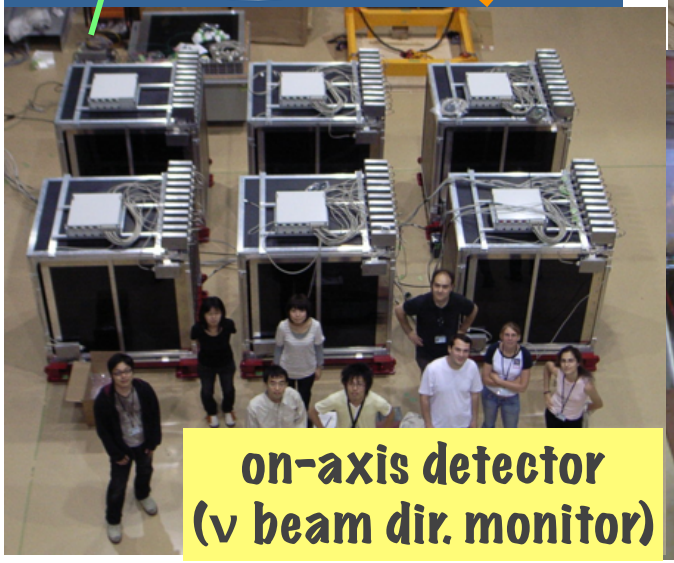
Status of preparation toward physics run

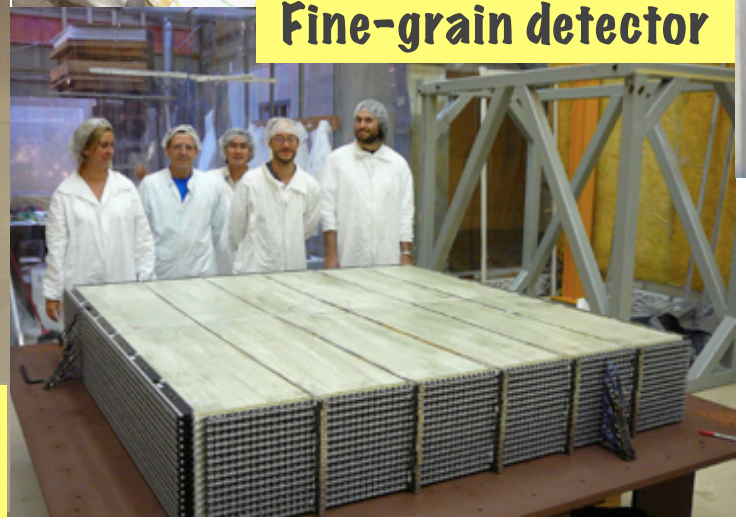
- Horn 2,3 installation and construction, installation of Near Detector(ND) are going on





Horn-2 installation (completed)





commissioning of ND will be started from Dec. '09

Prospects & Schedule

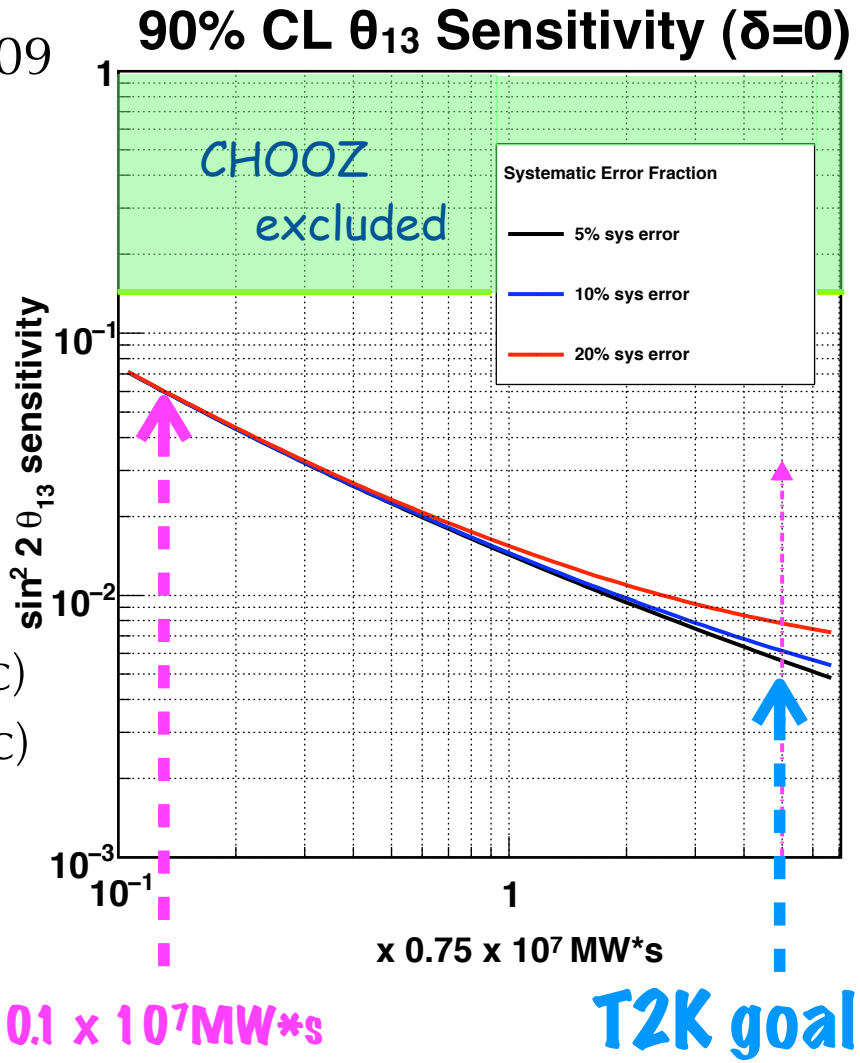
We aim for better sensitivity than the current limit by CHOOZ in 2010 as a first step

- T2K beam commissioning in fall-winter 2009
  - with full setup (3 Horns,NearDetector)
  - with high intensity beam
- physics run starts in Dec. 2009

*Next : We hope to discover ν_e appearance with 1-2 x 10^7 MW*sec in a few years*

- $\sin^2 2\theta_{13}$ = 0.05 (3σ discovery @ 1MW*sec)
  0.03 (3σ discovery @ 2MW*sec)

*Final results with 3.75 x 10^7 MW*sec*
(8×10^{21} p.o.t.)



Summary

- T2K neutrino oscillation experiment, our goals are
  - discover $\nu_\mu \rightarrow \nu_e$ appearance (a finite θ_{13})
    one order of magnitude sensitivity improvement from the current limit
  - ν_μ disappearance for precise measurement of $\sin^2 2\theta_{23}$, Δm^2_{23}
- **First beam commissioning was successfully completed**
  - neutrino production was confirmed with observing muon signal
  - confirmed basic functionality of the T2K beam-line
- Installation & construction works are going on toward physics run
- Aim for better sensitivity than the current limit by CHOOZ in 2010

backup

1. J-PARC outline, parameters and beam commissioning status

2. Issues to be solved:
RFQ, RCS RF cavity and MR magnet power supply

3. Plan: (1) Neutrinos (Fast Extraction)
(2) Hadrons (Slow Extraction)
(short term, middle term and long term)

M. Yoshioka's talk, "J-PARC Status and Plan"
@ CERN Workshop on New Opportunities in the Physics Landscape at CERN

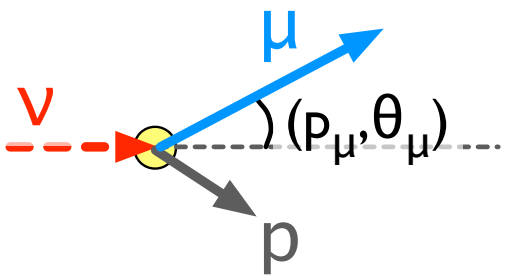
(1)T2K and beyond:
3-step Power Upgrade Scenario

Based on the assumption that three machine issues will be solved in a few years

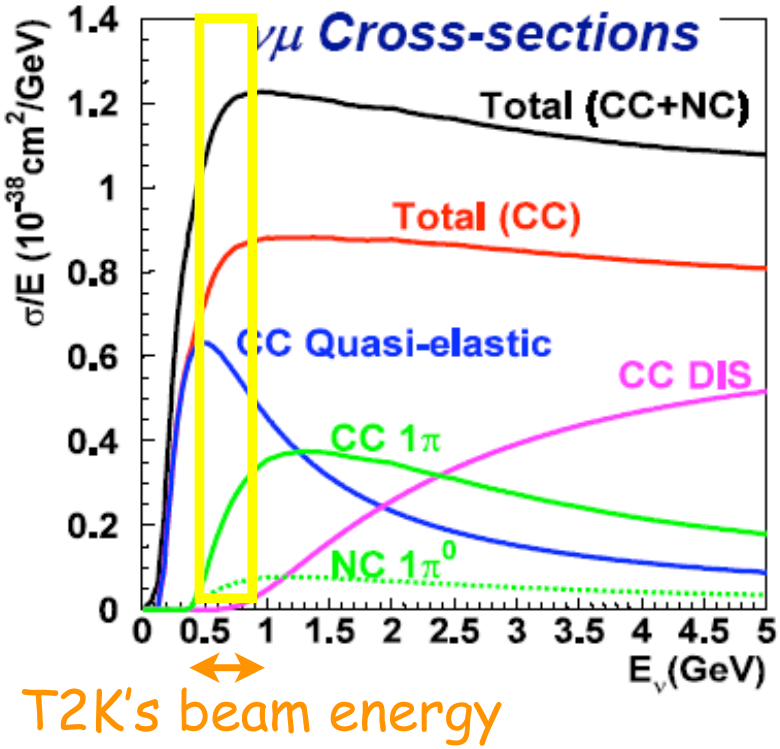
- **Short term plan (2009~2010)**
  - **FY2009 → Establish 30 kW run and 100kW trial**
  - **FY2010 → Establish 100kW (10^7 sec) and 300kW trial**
- **Middle term plan (2011~in a few years??)**
  Achieve design beam power (750kW)
  - **Understanding/solving space charge effect and collimator scenario/aperture**
  - **Improvement of MR magnet power supply to increase repetition rate**
  - **Linac 400 MeV energy recovery and upgrade of the RCS injection system**
- **Long-term plan toward power frontier (>MW)**
  - **KEK roadmap**

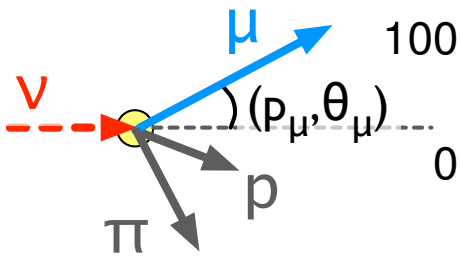
ν Energy Reconstruction

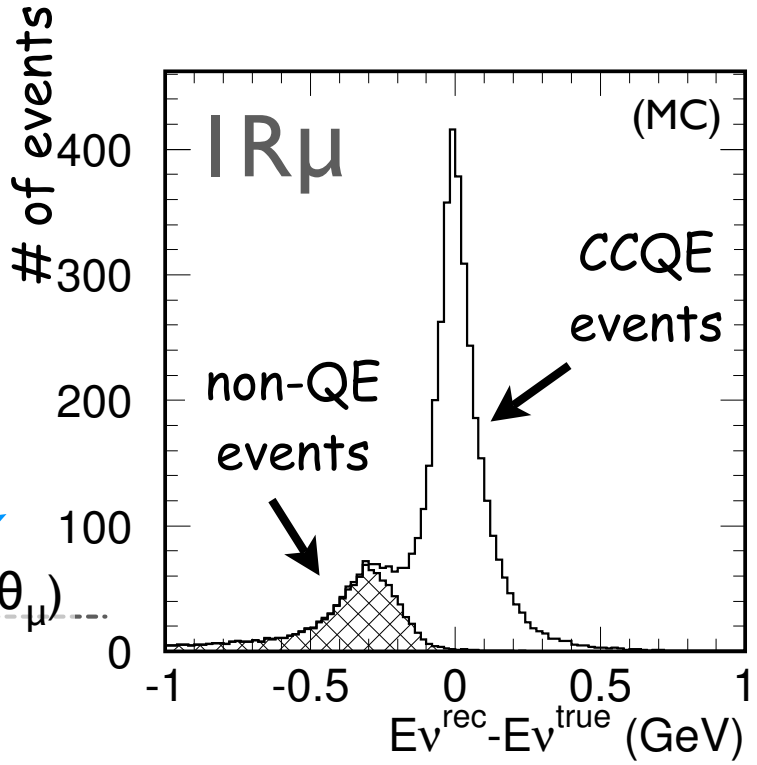
- ν's Energy reconstruction is possible for CC Quasi-Elastic interaction (CCQE: $\nu_{\mu(e)} + n \rightarrow \mu(e) + p$)



$$E_\nu^{\mathrm{rec}} = \frac{m_n E_\mu - m_\mu^2/2 - (m_n^2 - m_p^2)/2}{m_n - E_\mu + p_\mu \cos\theta_\mu}$$







θ_{13} measurement by ν_e appearance

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \Phi_{31}$$ θ_{13}

$$+ 8C_{13}^2 S_{12} S_{13} S_{23} (C_{12} C_{23} \cos\delta - S_{12} S_{13} S_{23}) \cos\Phi_{32} \sin\Phi_{31} \sin\Phi_{21}$$ CPC

$$- 8C_{13}^2 C_{12} C_{23} S_{12} S_{13} S_{23} \sin\delta \sin\Phi_{32} \sin\Phi_{31} \sin\Phi_{21}$$ CPV

$$+ 4S_{12}^2 C_{13}^2 (C_{12}^2 C_{23}^2 + S_{12}^2 S_{23}^2 S_{13}^2 - 2C_{12} C_{23} S_{12} S_{23} S_{13} \cos\delta) \sin^2 \Phi_{21}$$ solar

$$- 8C_{13}^2 S_{13}^2 S_{23}^2 (1 - 2S_{13}^2) \frac{aL}{4E} \cos\Phi_{32} \sin\Phi_{31}$$ matter effect (small in T2K)

L = 295 km, <E_ν> ~0.6GeV

$\sin\Phi_{21}$ ~ 0.05

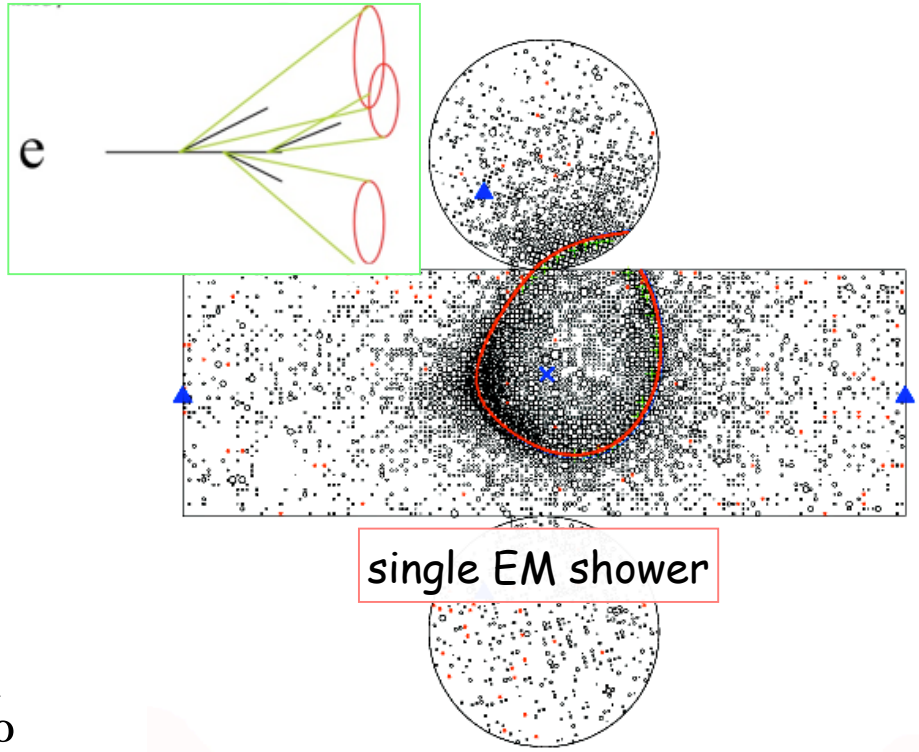
$$\delta \to -\delta, \; a \to -a \text{ for } P(\bar{\nu}_\mu \to \bar{\nu}_e)$$

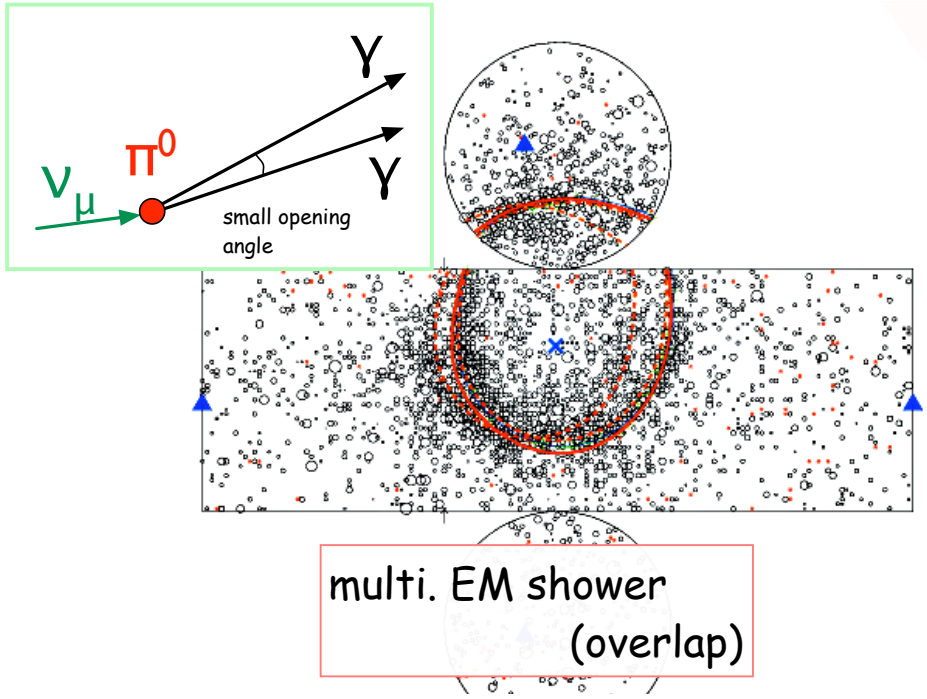
$$\frac{aL}{4E} = 7.6 \times 10^{-5} [\text{eV}^2] \left(\frac{\rho}{[\text{g/cm}^3]}\right) \left(\frac{E}{[\text{GeV}]}\right) \frac{L}{4E} \propto L$$

- $P(\nu_\mu \to \nu_e) \to \sin^2(2\theta_{13})$: some ambiguity due to unknown params.
- It is possible to measure CPV by comparing ν and $\bar{\nu}$

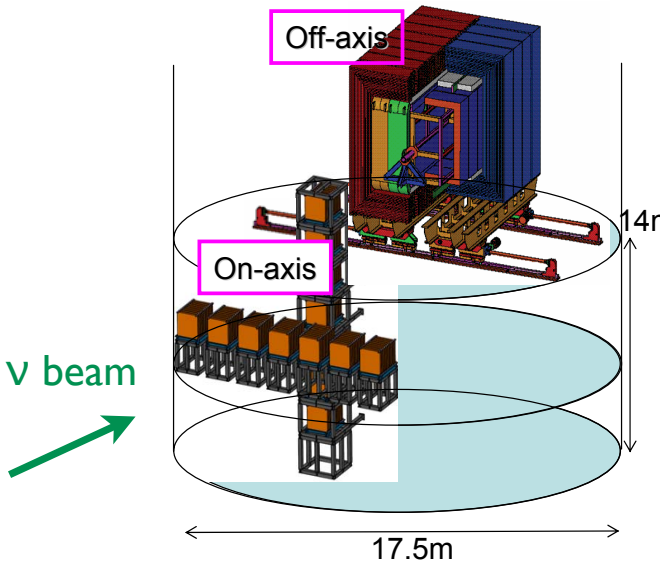
ν_e appearance search

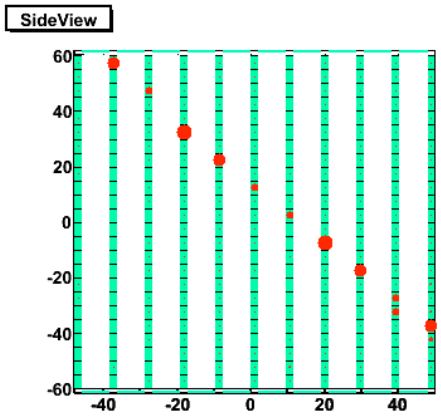
- Signal : e^- from ν_e CCQE int.
- Background
  - intrinsic ν_e in the ν_μ beam (0.4% of ν_μ at peak energy)
  - NC $1\pi^0$ interaction
    - π^0 misidentified as e
    - further e/π^0 separation cut & understanding efficiency

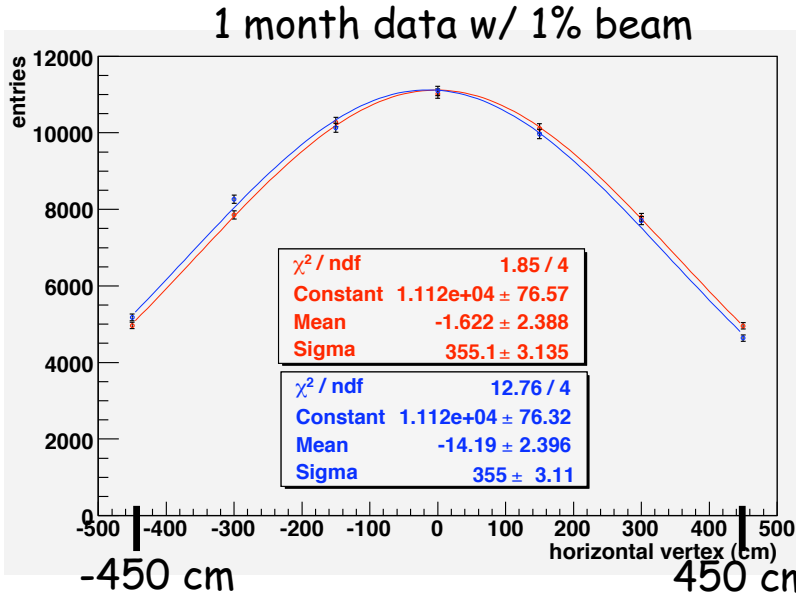




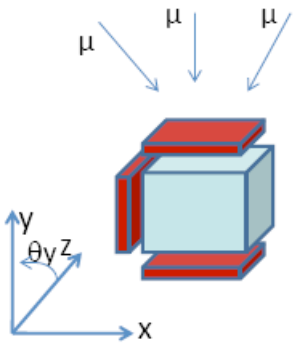
ν beam direction monitor

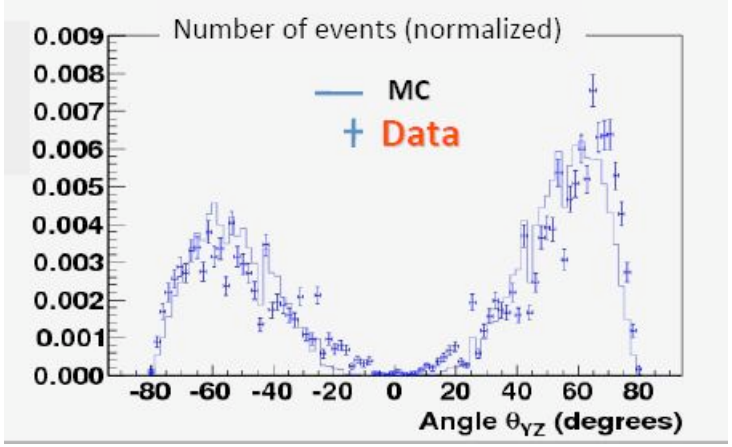






- first look in agreement with simulation

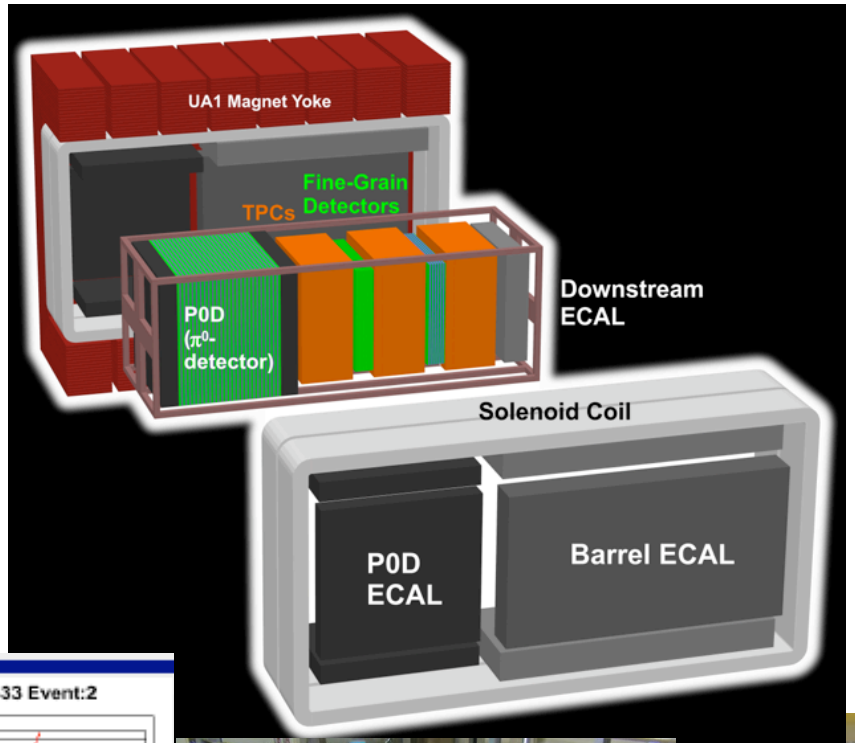




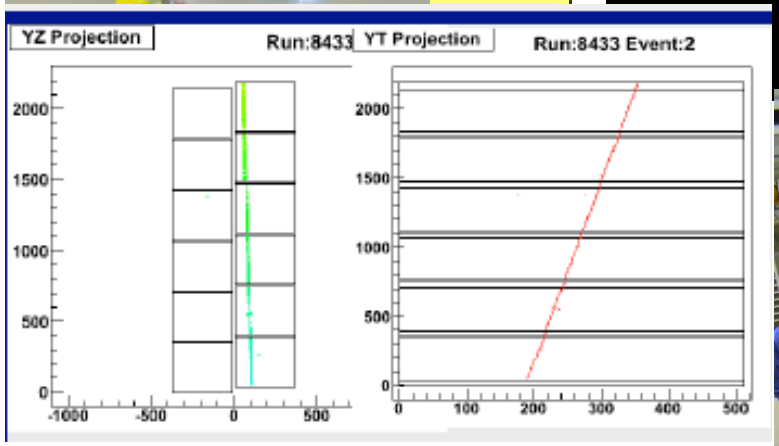
- Tracking plane efficiency 99.5 ± 0.6 %

Off-axis detectors

TPC



Side Muon Range detector



construction/installation/ hardware test is going on

PiO detector

Electro-magnetic calorimeter