# T2K実験の現状

2010年2月9日

柴田政宏 (KEK)
For the T2K collaboration

# Outline

1. Introduction
   - Motivation, setup, sensitivity of the T2K experiment
   - Neutrino facility and detectors
2. Neutrino facility commissioning
3. Prospect of $\theta_{13}$ search
4. Summary

# 1. Introduction

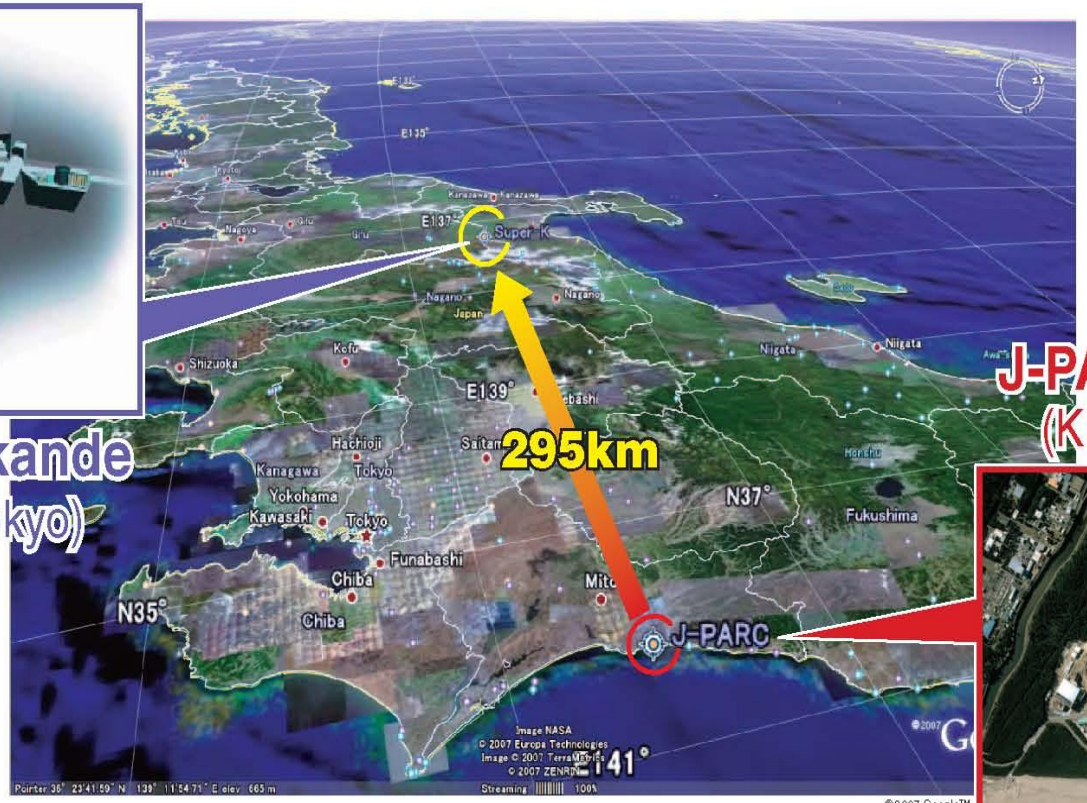
# Physics motivation

- To understand neutrino mixing
  - Discovery of finite $\theta_{13}$ through $\nu_e$ appearance
    - $\theta_{13} \neq 0 \rightarrow$ CP violation measurement in the future
      - Could be a hint to understand how matter dominated universe was made
  - Precise measurement of $\theta_{23}$ and $\Delta m^2_{23}$ through $\nu_\mu$ disappearance
    - $\theta_{23}$ is maximal mixing?

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

# Tokai to Kamioka experiment (T2K)

Super-Kamiokande
(ICRR, Univ. Tokyo)




J-PARC Main Ring
(KEK-JAEA, Tokai)

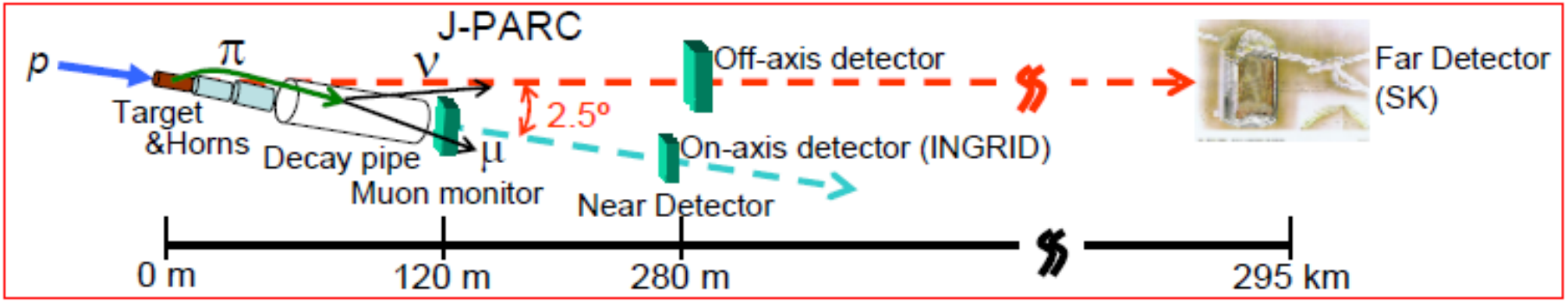
- Long base line (295 km) neutrino oscillation experiment with
  - high power (MW class) proton beam of J-PARC Main Ring
  - world largest water Cherenkov neutrino detector (Super-Kamiokande)
  - off axis beam to achieve narrow energy band and low background

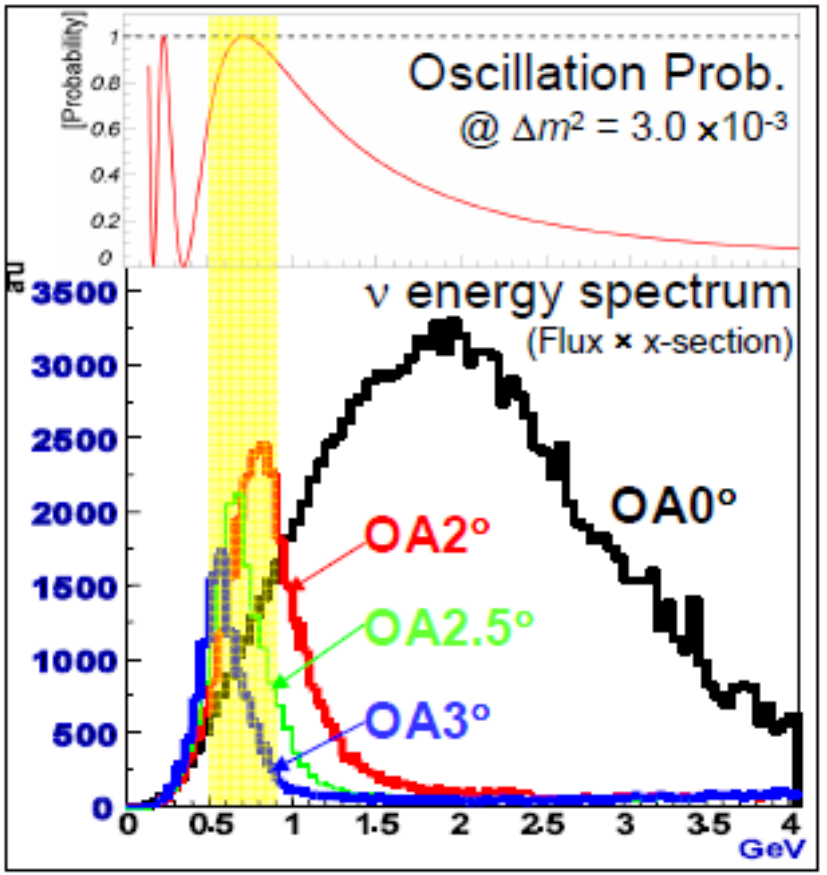
# Collaboration of the T2K experiment


~ 400 members from 12 Countries

Japan, US,  Canada, France, UK, Switzerland, Poland, Korea, Russia, Spain, Italy, Germany

# Setup of the T2K experiment



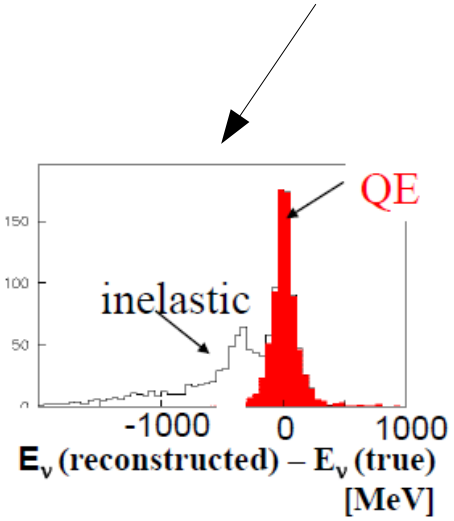



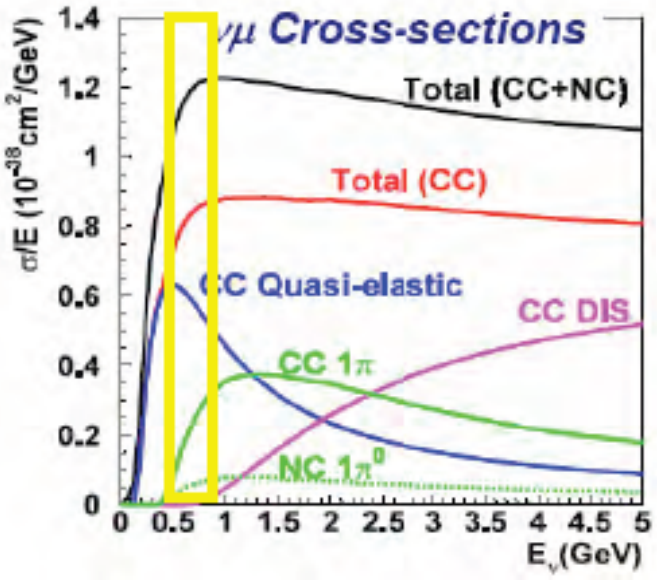

- Off axis beam (2.5°)
  - Peak energy ~600MeV
  - Narrow energy spectrum
- Expected event
  - 1700 CC-interaction/22.5kt/3000h (30GeV, 750kW, no oscillation)
- $\nu_e$ contamination
  - 0.4% @ peak energy

# Neutrino energy reconstruction

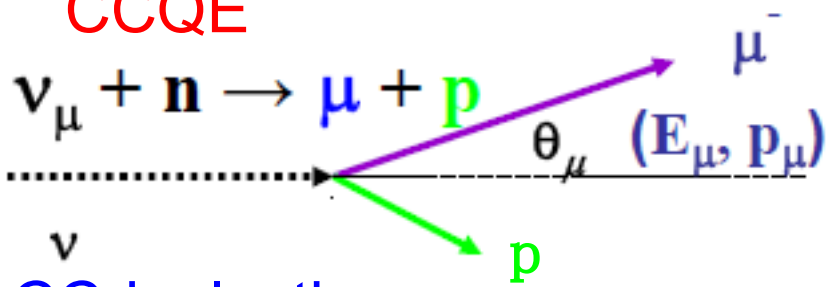
- Interaction with nucleon in detector material is utilized.
- Neutrino energy is derived from Charge Current Quasi Elastic scattering (CCQE).

$$E_\nu^{rec} = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

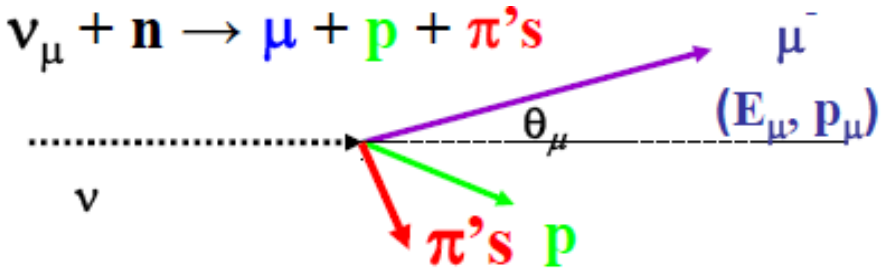


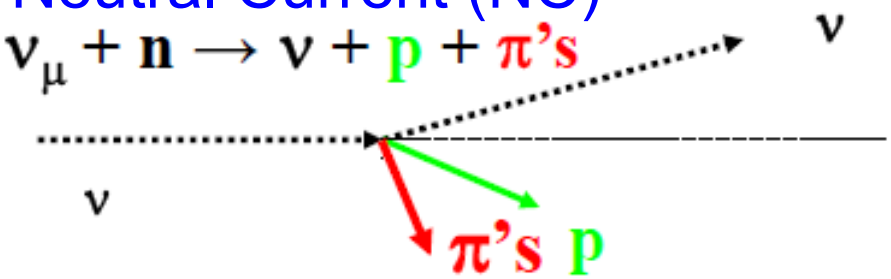

CCQE




CC-inelastic

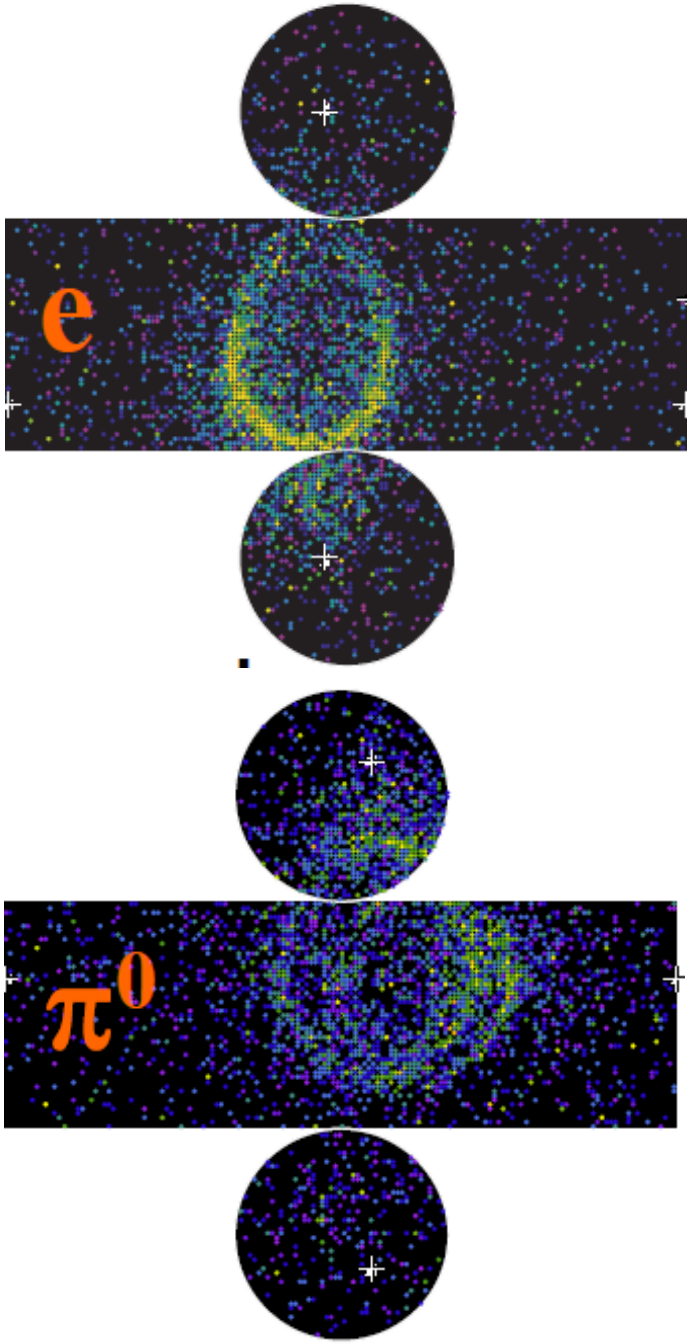



Neutral Current (NC)



# $\nu_e$ appearance

- Signal
  - $e^-$ from CCQE interaction
- Background
  - Intrinsic $\nu_e$ in $\nu_\mu$ beam
  - $\pi^0$ misidentification as $e^-$ (from NC1$\pi$ interaction)

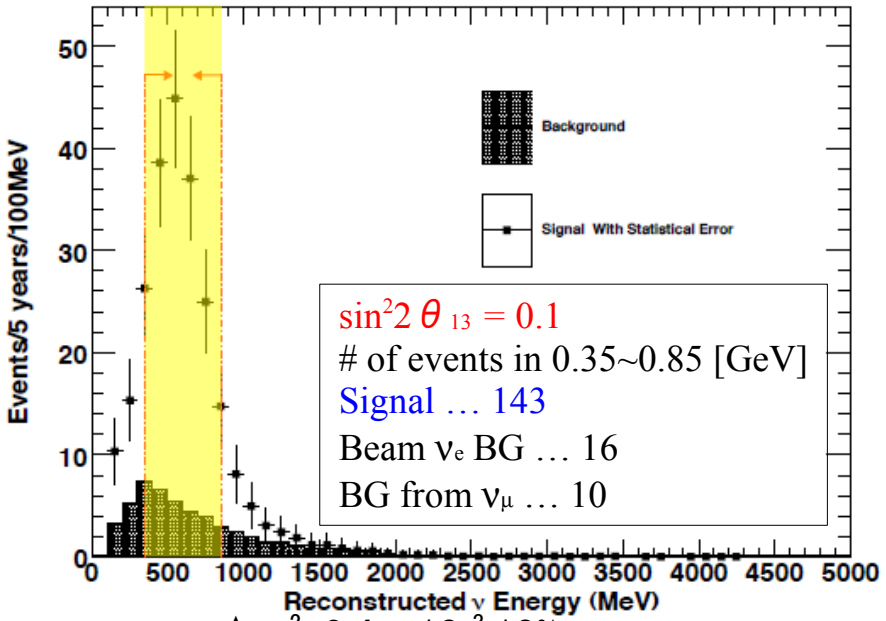


# Sensitivity of $\theta_{13}$

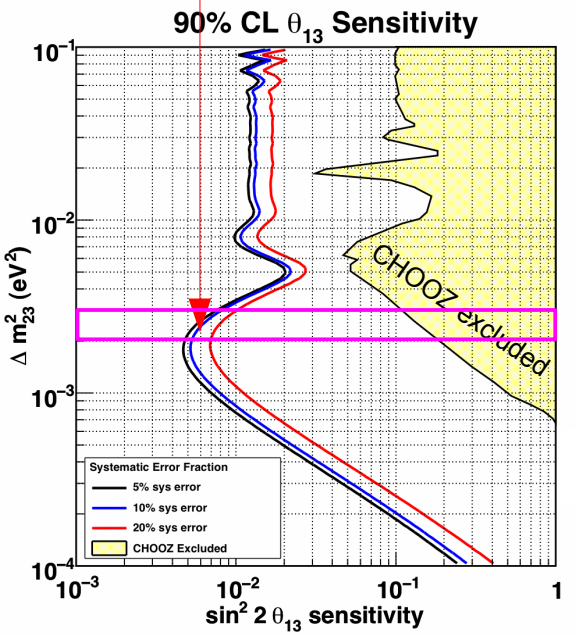
$$P(\nu_\mu \to \nu_e) \approx \sin^2 2\theta_{13} \sin^2 2\theta_{23} \sin^2\left(\frac{1.27\Delta m^2_{31} L}{E}\right)$$

CHOOZ
$\sin^2 2\theta_{13} < 0.13$
$(\Delta m^2 = 2.8 \times 10^{-3})$
@ 90% C.L.

T2K goal
$\sin^2 2\theta_{13} \sim 0.006$ @ 90% C.L.
$(\Delta m^2 = 2.4 \times 10^{-3}$, 10% sys. error)



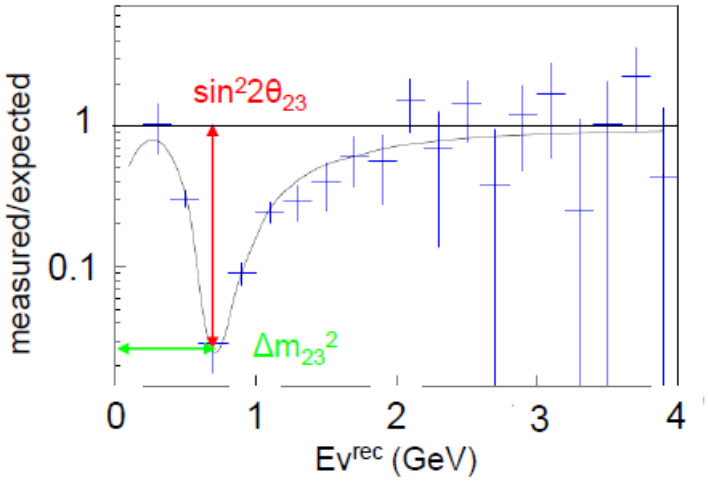

$\Delta m^2 = 2.4 \times 10^{-3}$, 10% sys. error




$8 \times 10^{21}$ POT@30GeV

# Sensitivity of $\theta_{23}$ and $\Delta m^2_{23}$

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




Current value

$\sin^2 2\theta_{23} > 0.92$ @ 90% C.L. (SK)

$|\Delta m^2_{23}| = 2.43 \pm 0.13 \times 10^{-3}\ \mathrm{eV}^2$

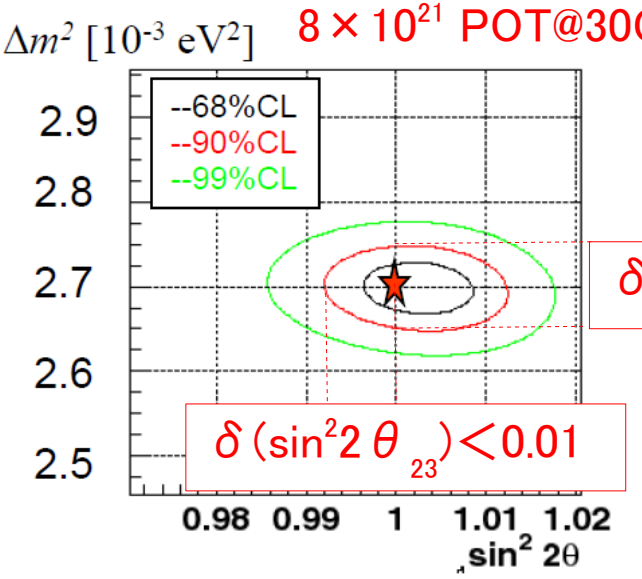
@ 68% C.L. (MINOS)

T2K goal

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

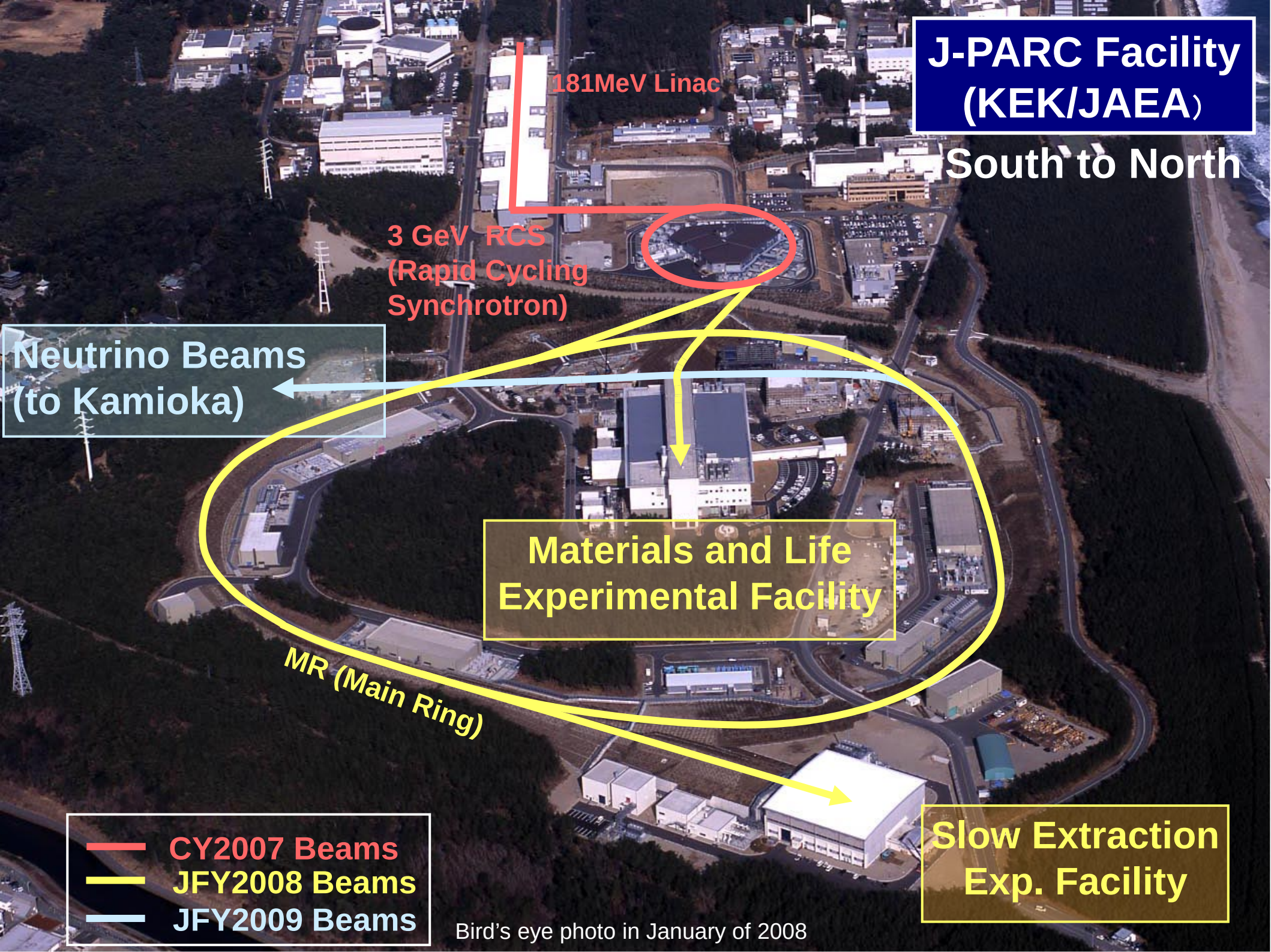
$\delta(\Delta m^2_{23}) < 10^{-4}\ \mathrm{eV}^2$

@ 90% C.L.

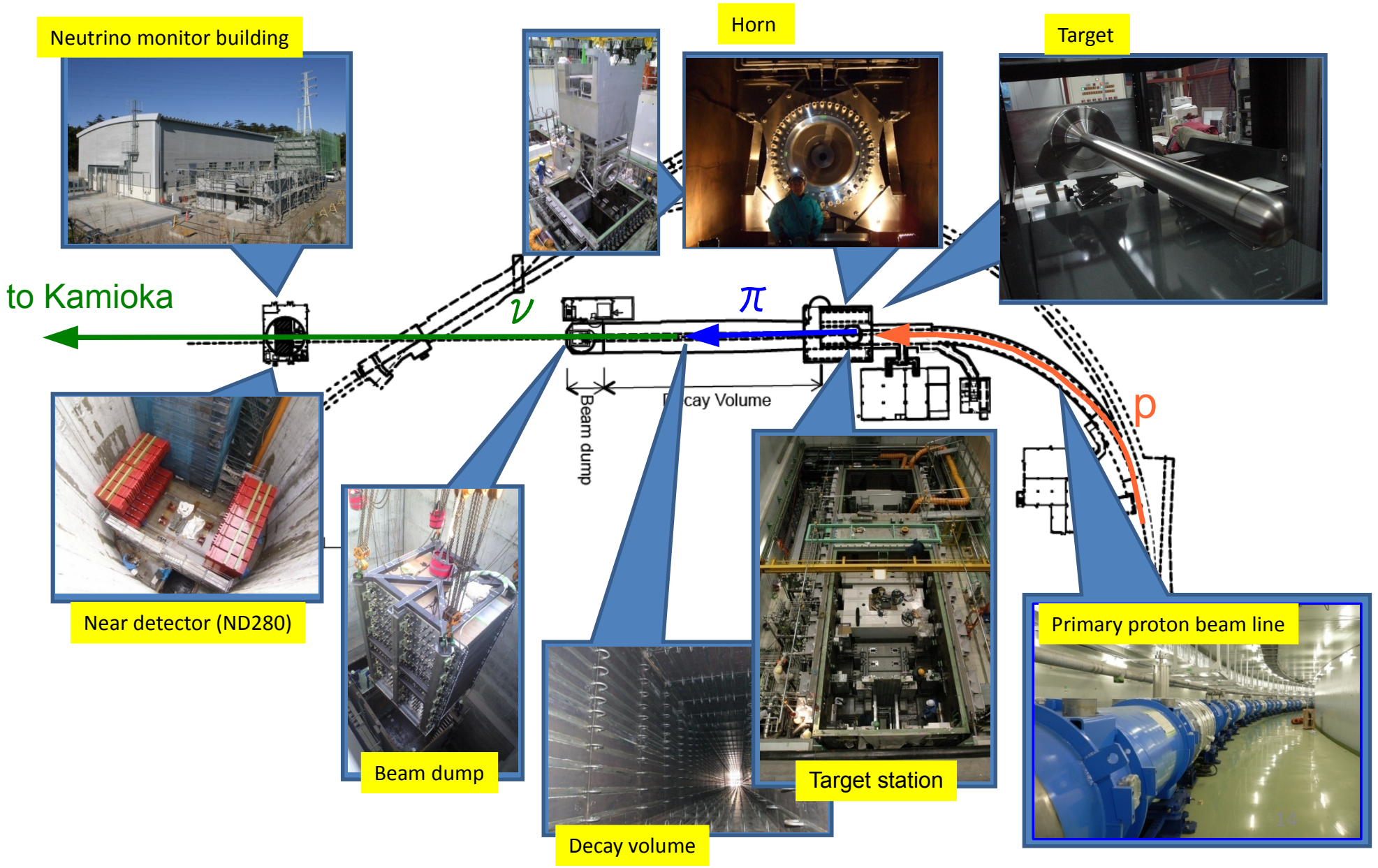



(stat. error only)

# Neutrino facility
# and
# Neutrino detectors

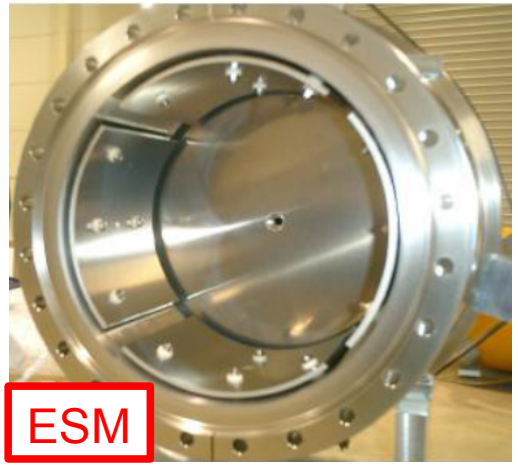

J-PARC Facility
(KEK/JAEA)
South to North
181MeV Linac
3 GeV RCS
(Rapid Cycling
Synchrotron)
Neutrino Beams
(to Kamioka)
Materials and Life
Experimental Facility
MR (Main Ring)
Slow Extraction
Exp. Facility
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

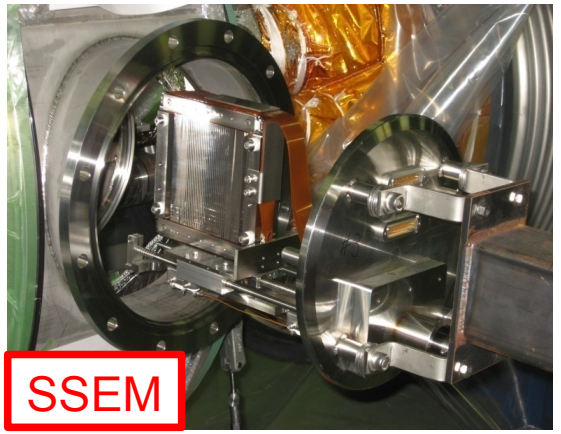
# Neutrino facility

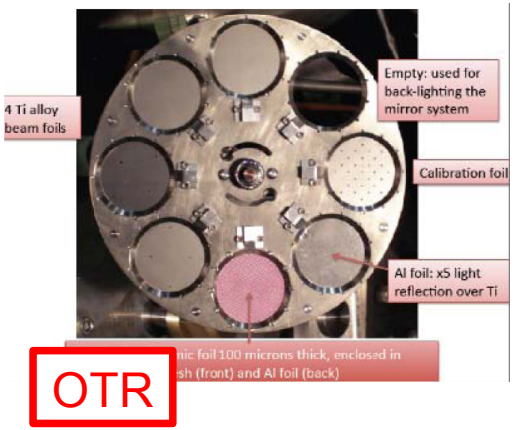


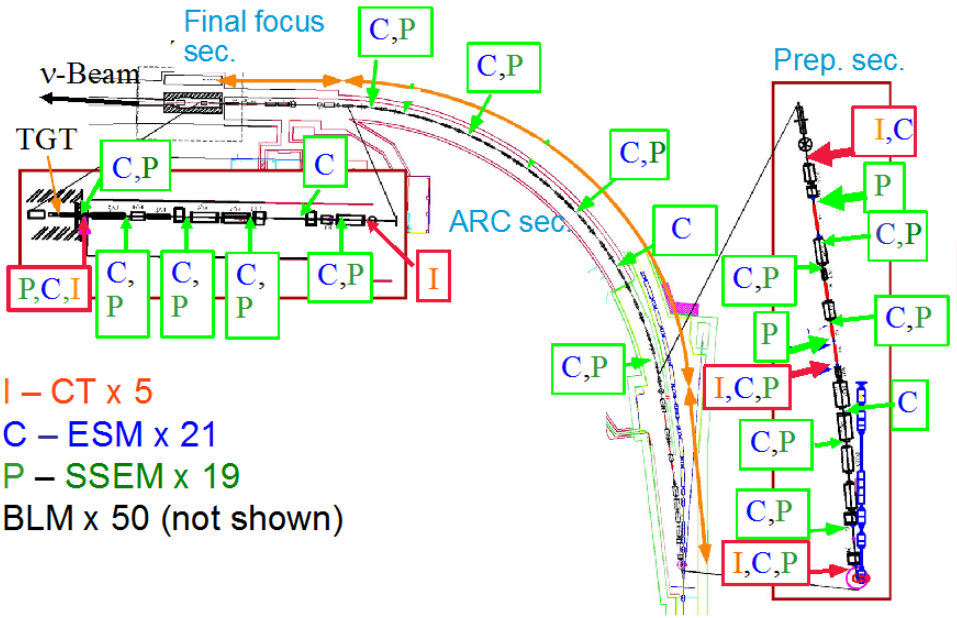
# Proton beam monitors

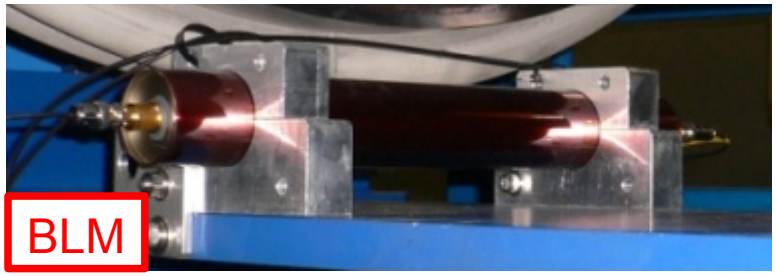
- Intensity monitor: current transformer (CT)
- Position monitor: electro static monitor (ESM)
- Profile monitor:
  segmented secondary emission monitor (SSEM)
  optical transition radiation monitor (OTR)
- Beam loss monitor (BLM): ionization chamber

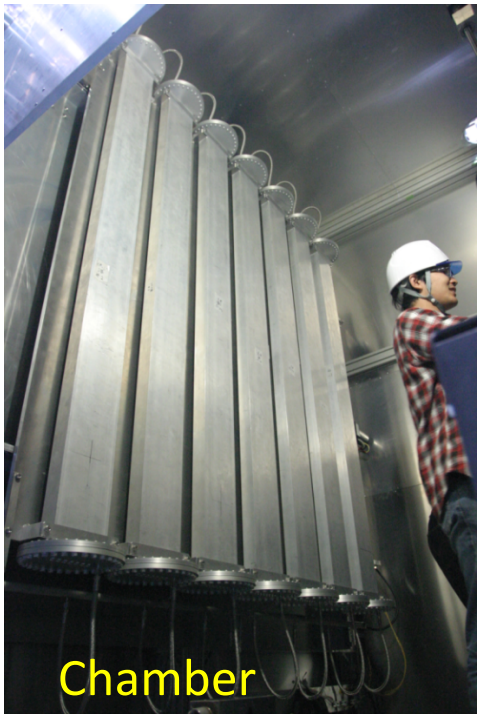



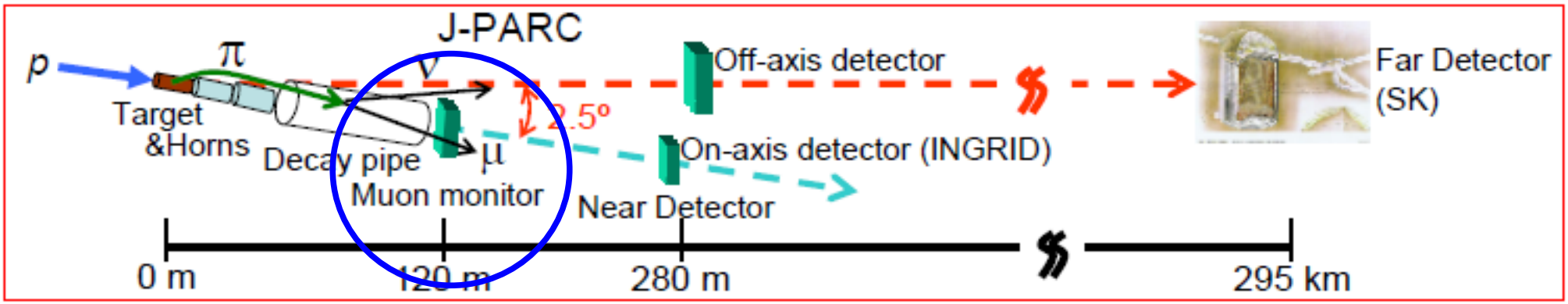



# Muon monitor

- Muon monitor measures direction, profile and intensity of muons produced with neutrinos.
- Muon monitor is an array of ion chambers and Si PIN photodiodes installed downstream of the beam dump.

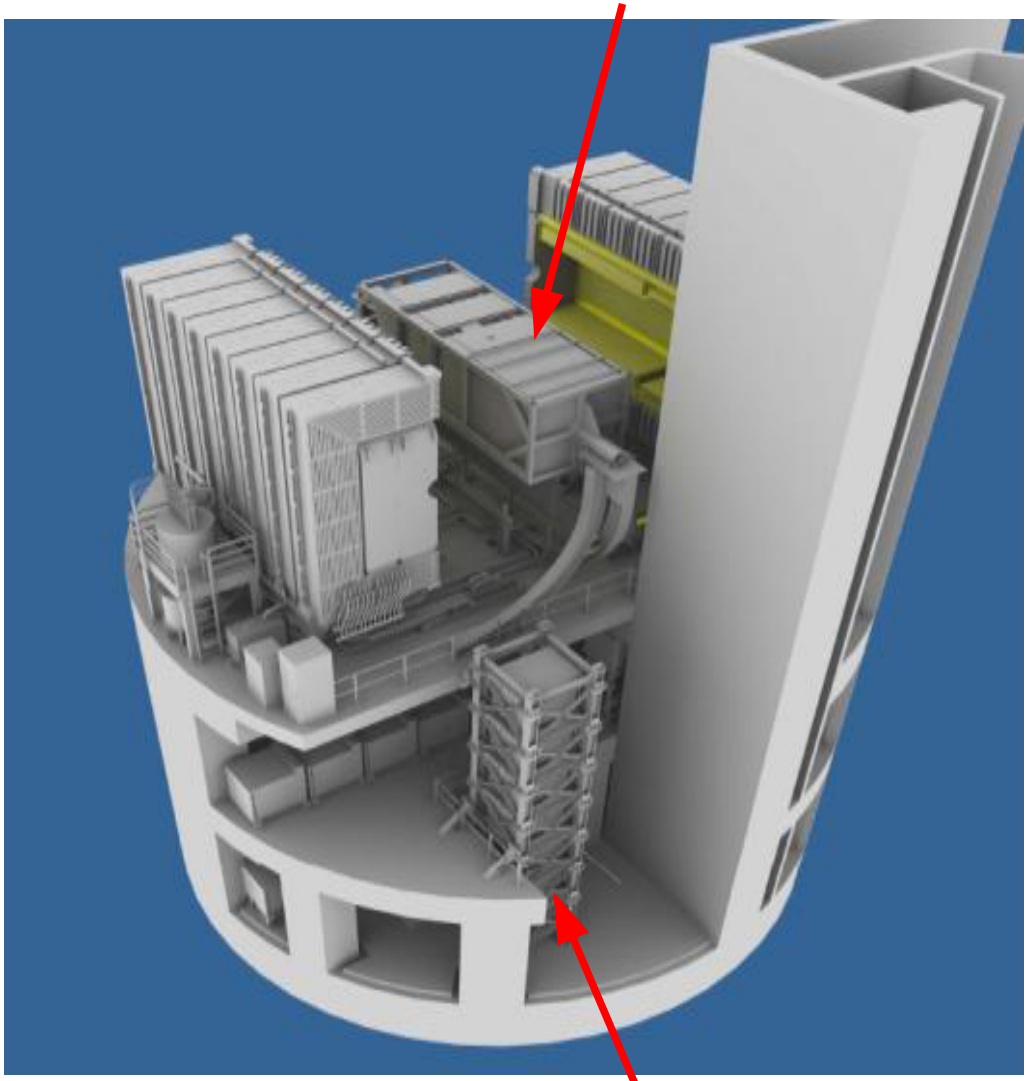




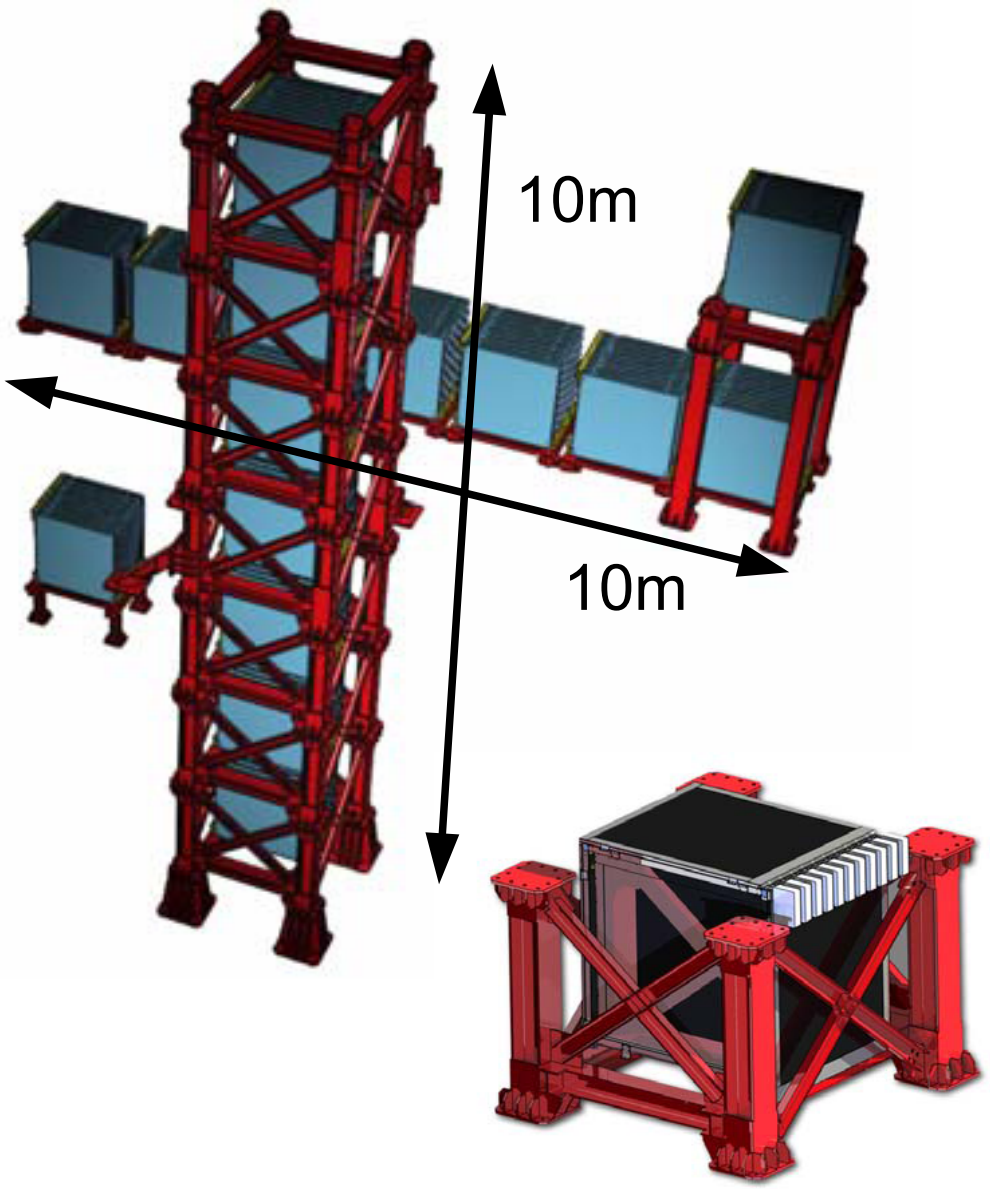


# Near detector (ND280)

- On axis detector
  - measure direction and intensity of neutrino beam
- Off axis detector
  - measure flux and energy spectrum of neutrino beam
  - measure $\nu_e$ contamination
  - measure cross section of neutrino–nucleon interaction

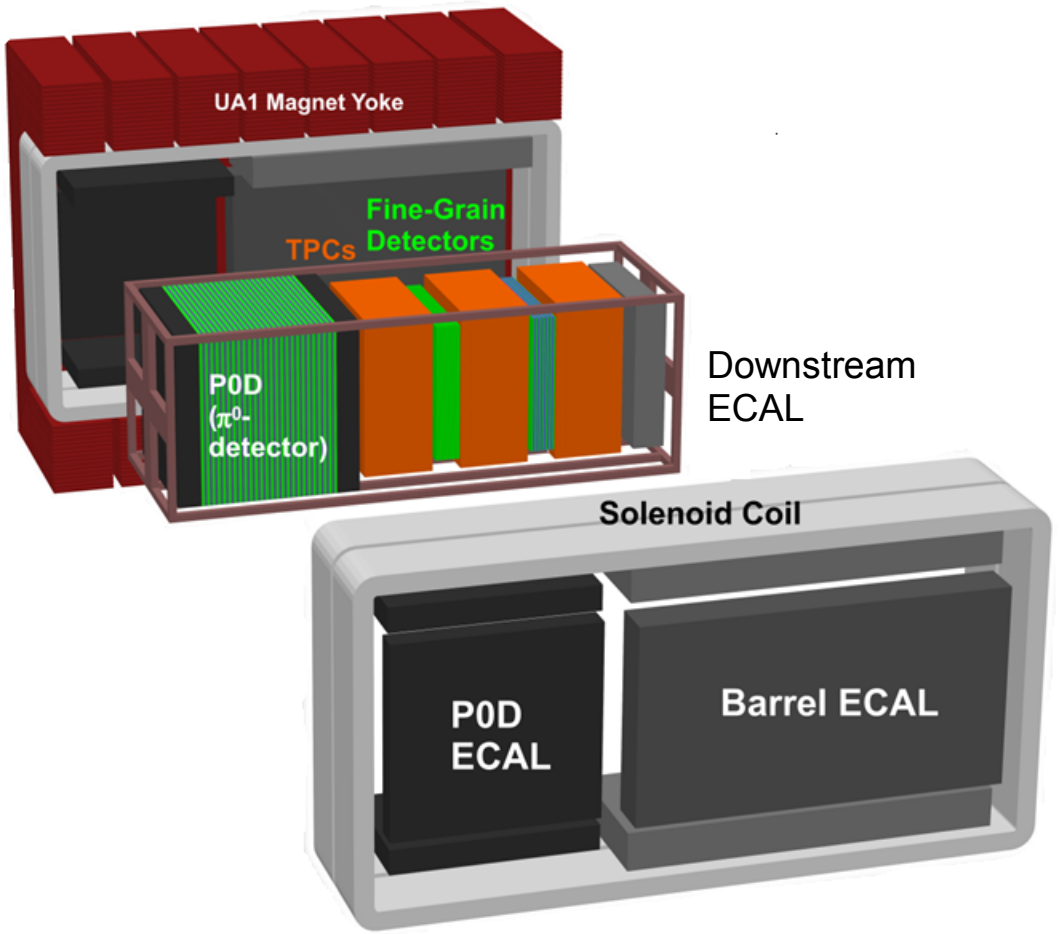


# On axis detector (INGRID)



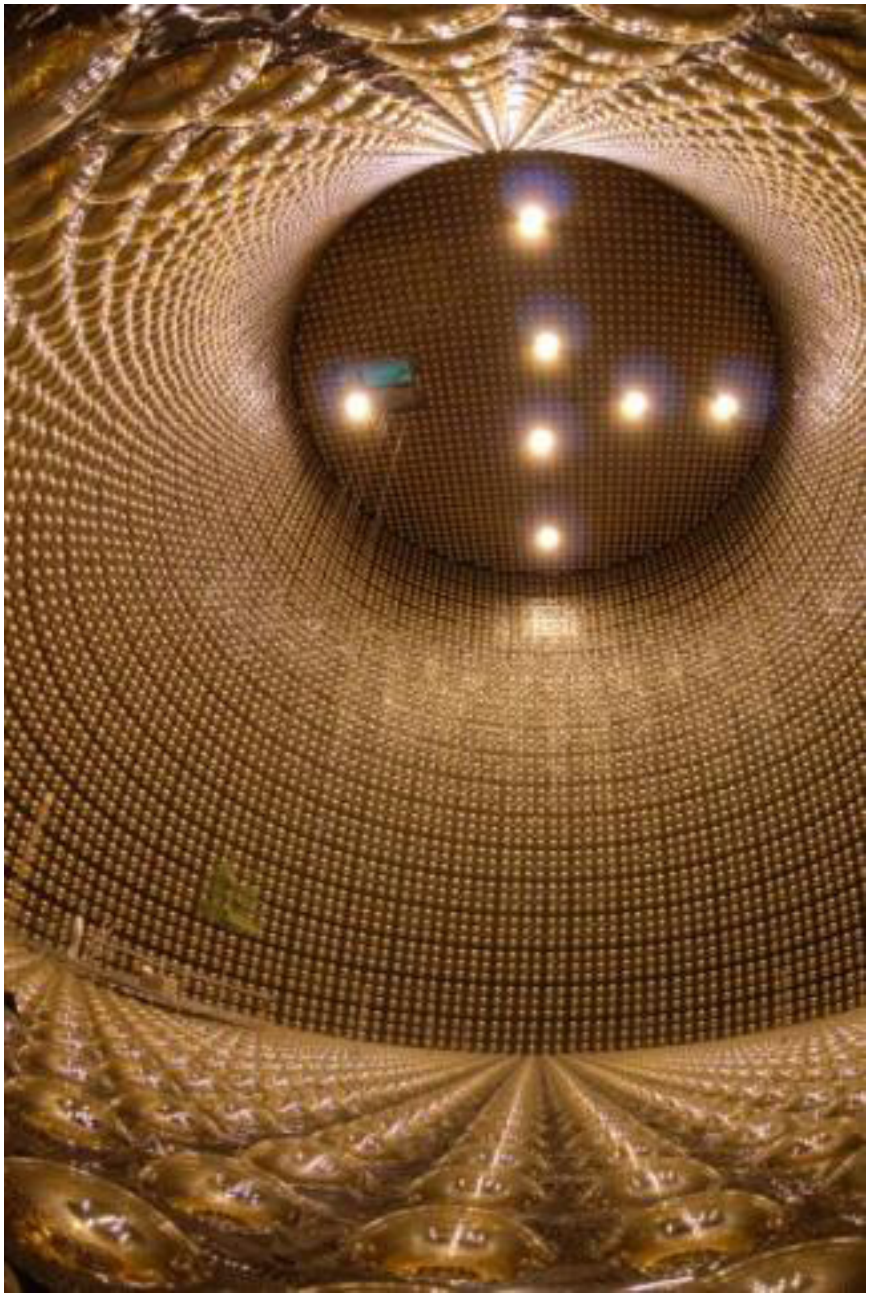

- 16 modules cover 10m×10m region.
- Each module consists of 9 iron targets, 11 scintillator planes and veto planes.
- The scintillator plane consists of scintillator, WLS fiber and MPPC.

# Off axis detector




- P0D
  - High statistics $\pi^0$ measurement
- Tracker (TPC + FGD)
  - Charged particle tracking
  - FGD also measures $\pi^0$
- ECAL
  - Measure $\pi^0$ with P0D and FGD
  - Photon veto
- SMRD
  - Measure range of muons
  - Veto from outside

# Far detector (Super-Kamiokande)

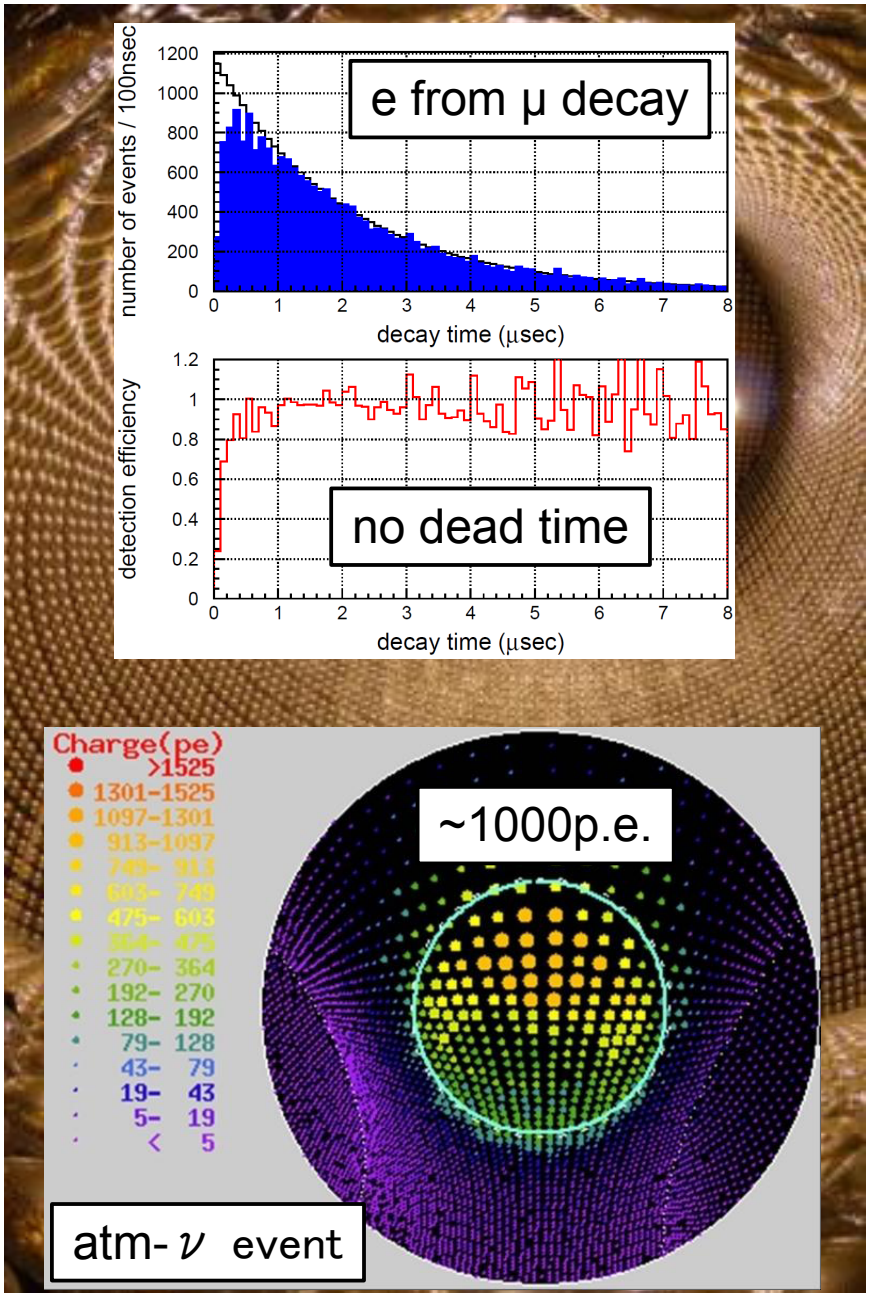


- 50 kt water Cherenkov detector with 13,031 photo-multipliers

  (fiducial volume: 22.5 kt)

- New electronics installed in summer of 2008 (SK-IV)
  - Stable and dead time less DAQ
  - Wide charge dynamic range
- DAQ has been stable and detector calibrations have been performed
- SK is ready for T2K physics run

# Far detector (Super-Kamiokande)

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# 2. Neutrino facility commissioning

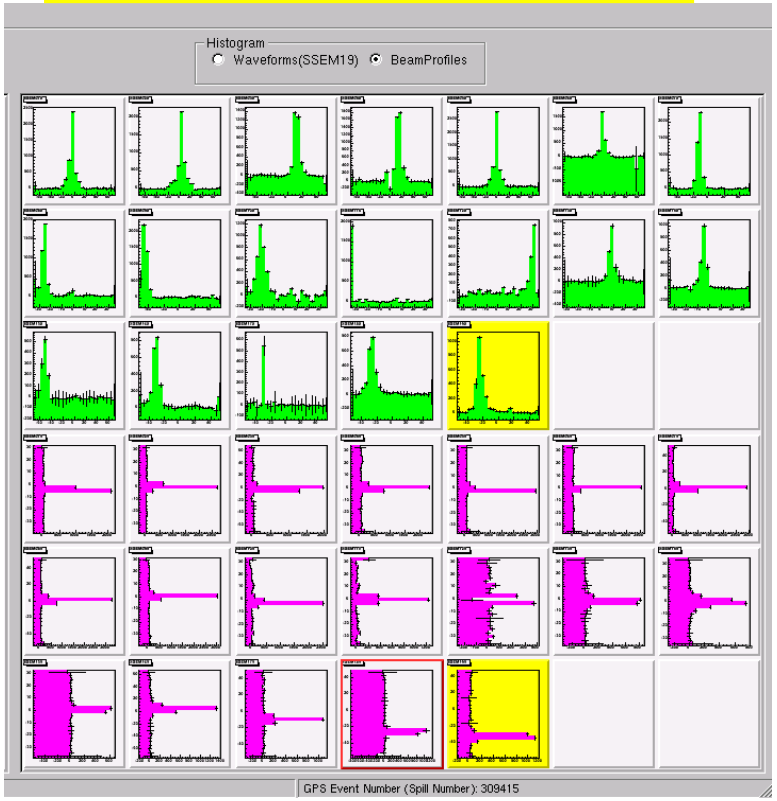
# First year of the T2K experiment

- April Commissioning started
  First neutrino production
- May Commissioning
- June~October Summer shutdown
  Horn2, 3 installed
  All INGRID modules installed
- November Commissioning resumed
  First event in INGRID
  Off axis detector became ready for beam
- December Commissioning
  First event in off axis detector

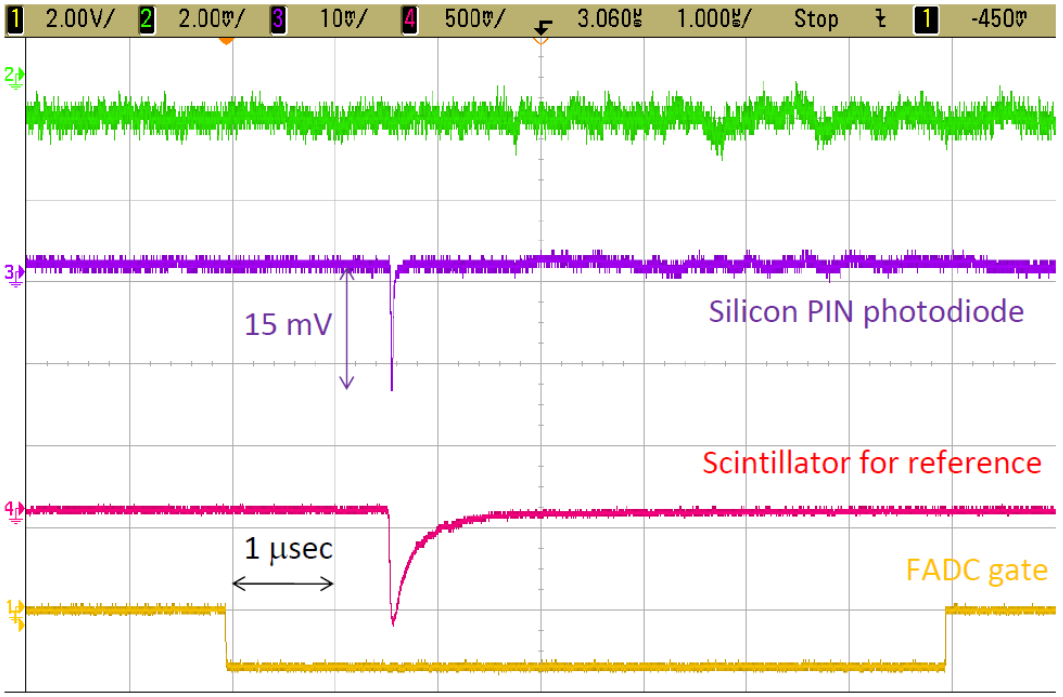
# First beam commissioning 2009.4.23

# First beam commissioning 2009.4.23 (first shot)

Proton profile monitor (SSEM)



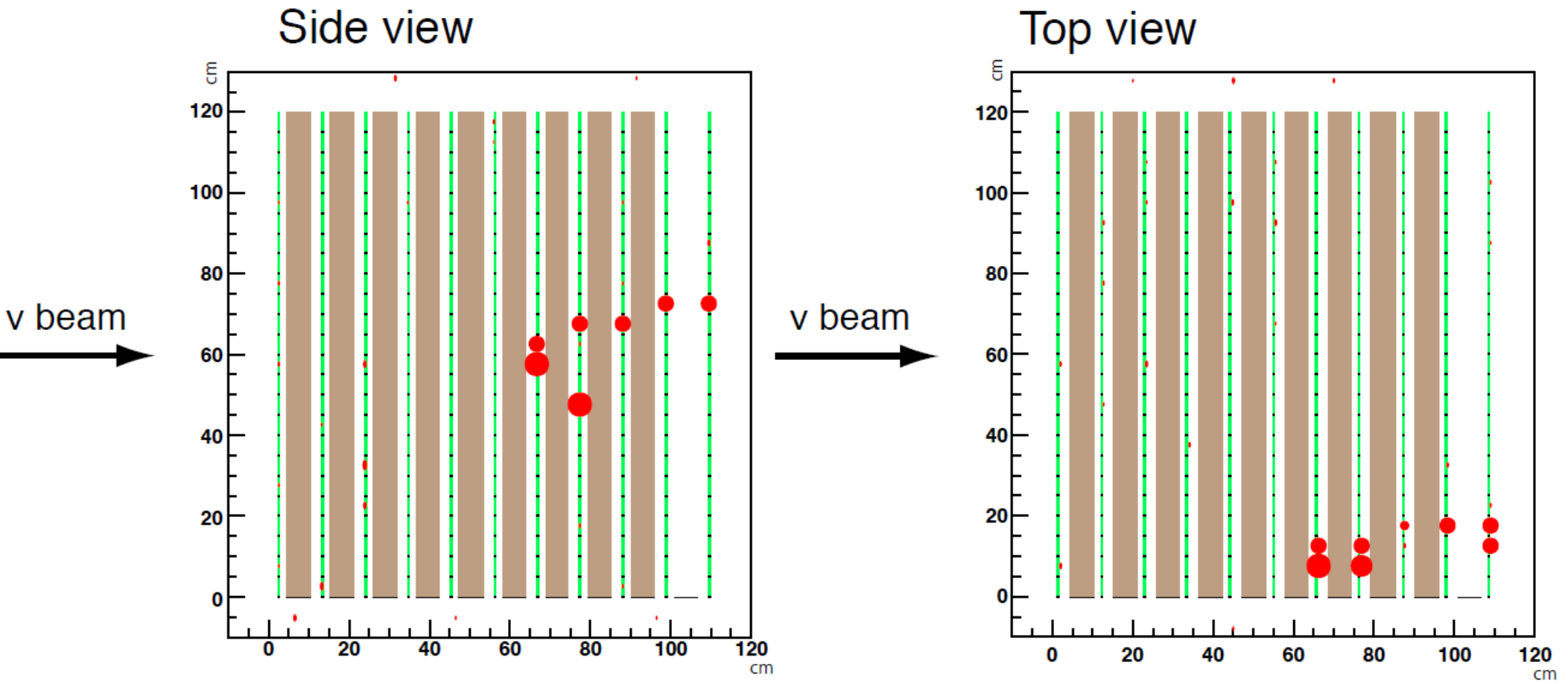

Muon monitor



# First neutrino event in INGRID

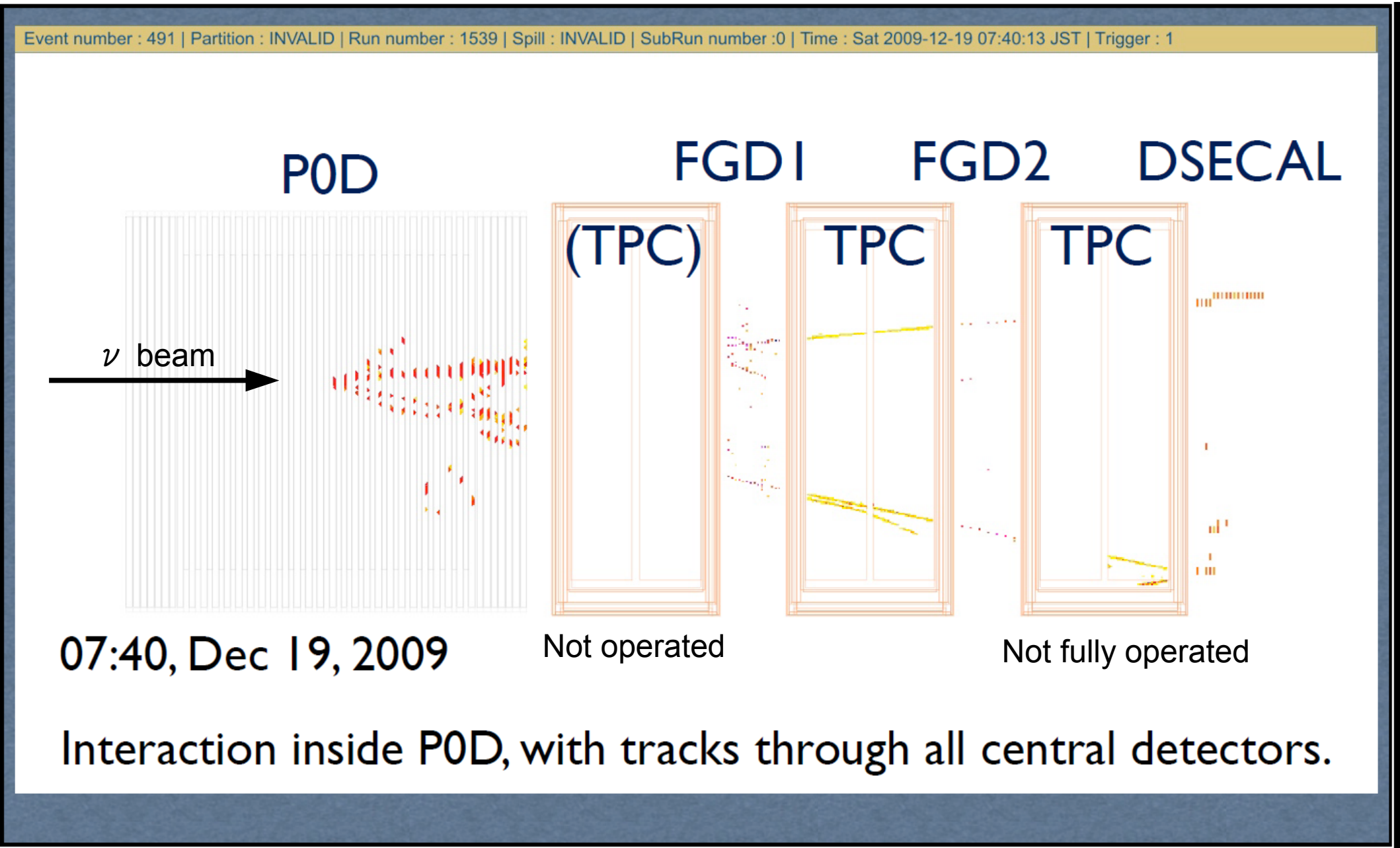
# First neutrino event in INGRID

Nov. 22, 2009
20:25:48 JST




MR Run #27, Shot #19655
T2K Spill# 241792

# First neutrino event in off axis detector

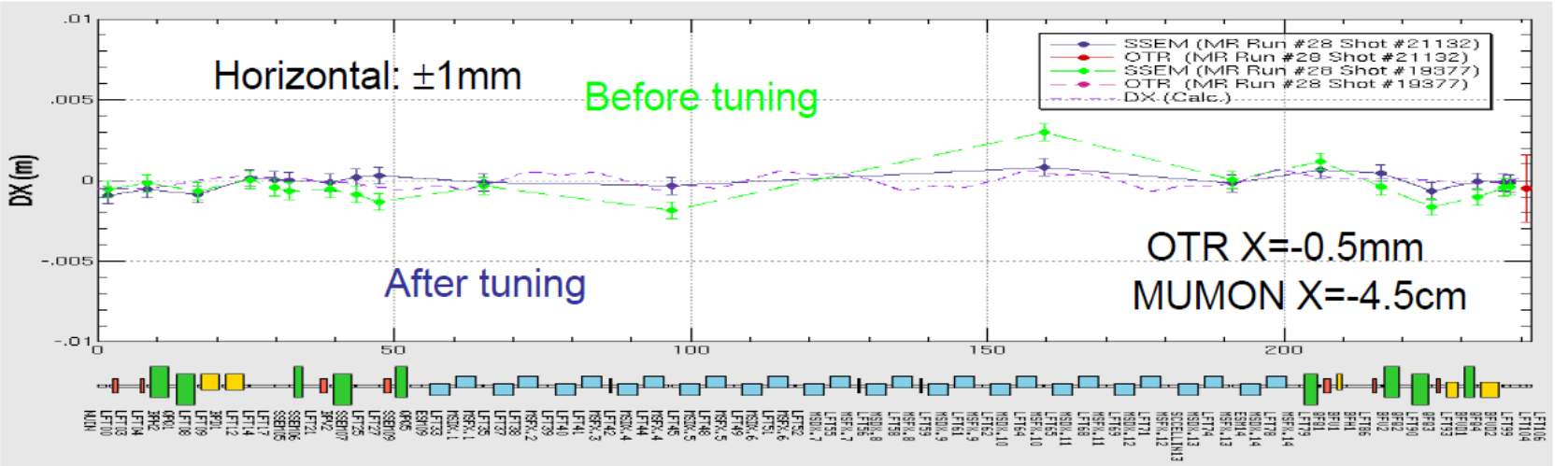


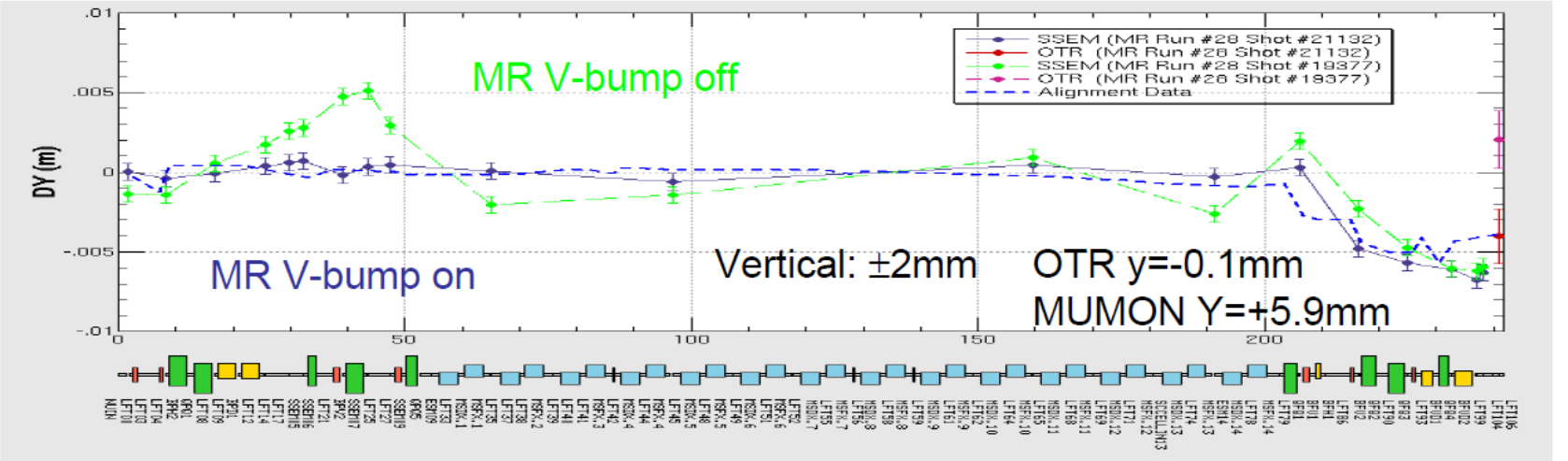

Interaction inside P0D, with tracks through all central detectors.

# Achievements of commissioning (by the end of 2009)

- Basic functionality of beam monitors was confirmed.
- Near detector observed neutrino events.
- Proton beam orbit was tuned within 2mm. No significant beam loss was observed.
- Integrated proton number: $3.9\times10^{16}$ (20 days operation)
- Max. power: 20kW (continuous), 50kW (one shot operation)
- Beam stability was checked through 30 min. continuous operation.
  (intensity < 1%, position @ most downstream < 0.2mm, direction @ mumon < 1mrad, beam width @ target < 9%)
- Focusing effect of the electromagnetic horns was confirmed.

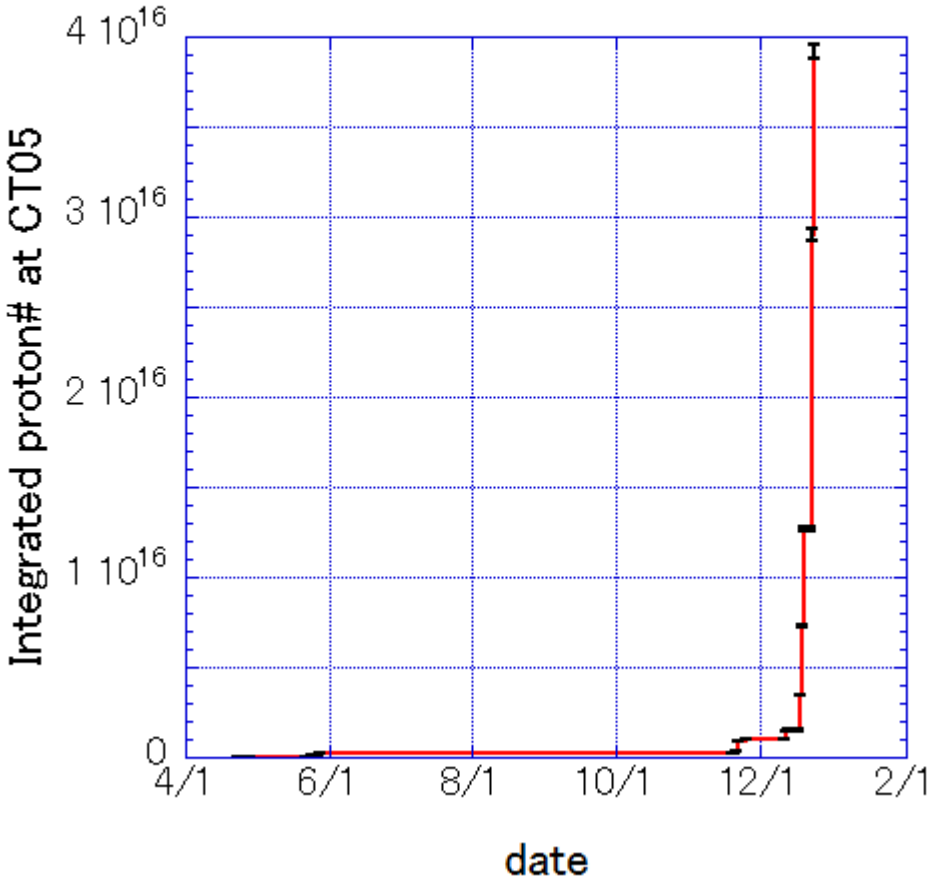
# Orbit tuning of proton beamline

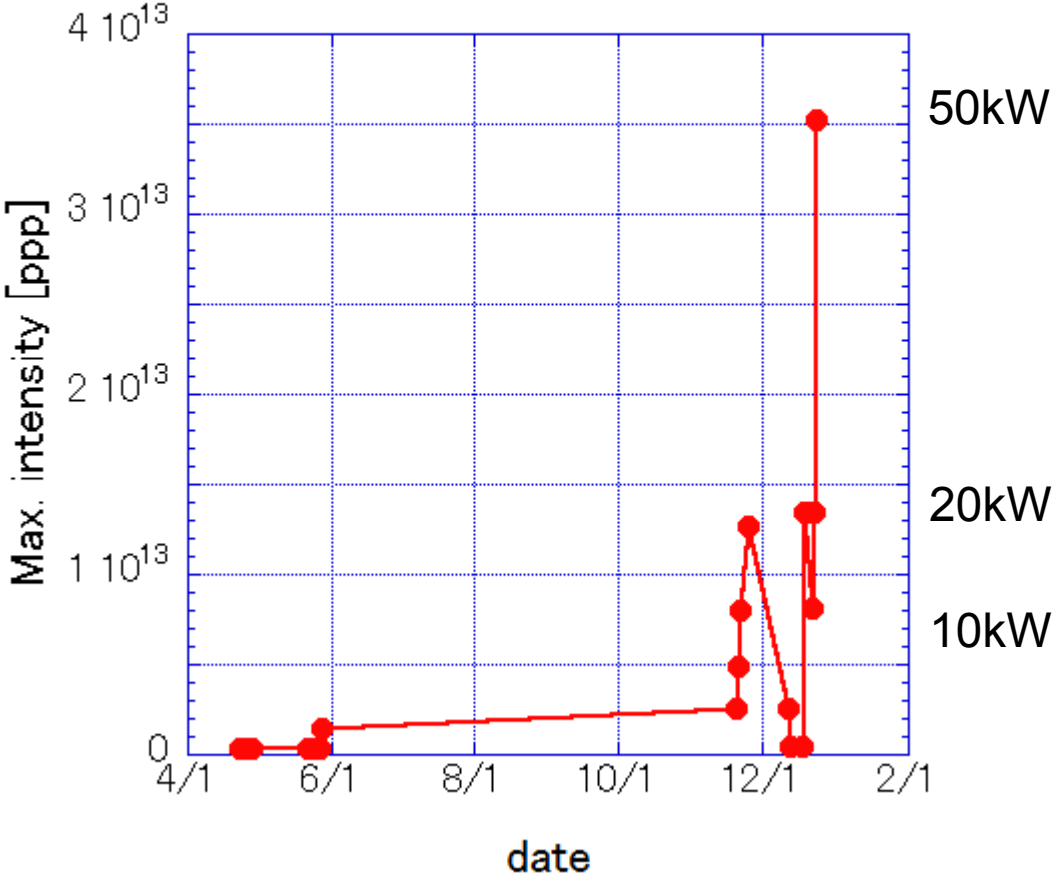



- No significant beam loss was observed.

# Integrated proton number & max. intensity



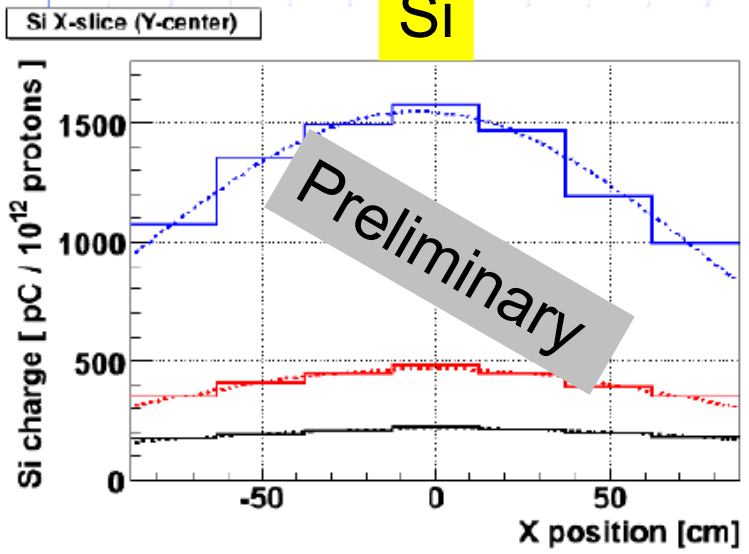




- Integrated proton number: $3.92 \pm 0.04 \times 10^{16}$
- Max. intensity: 20kW (continuous), 50kW (single shot)

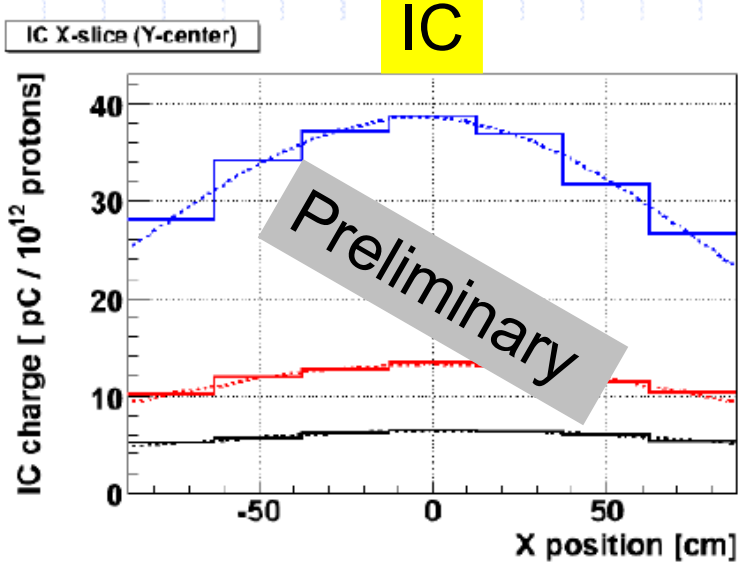
# Focusing effect of horn

| | |
|---|---|
| 3 horns, 320 kA | (shot# 47577), 2.16 x $10^{12}$ ppb, 6 bunch |
| 1st horn, 275 kA | (shot# 47987), 2.10 x $10^{12}$ ppb, 6 bunch |
| no horn, 0 kA | (shot# 48704), 2.13 x $10^{12}$ ppb, 6 bunch |

Si




IC




×7.1

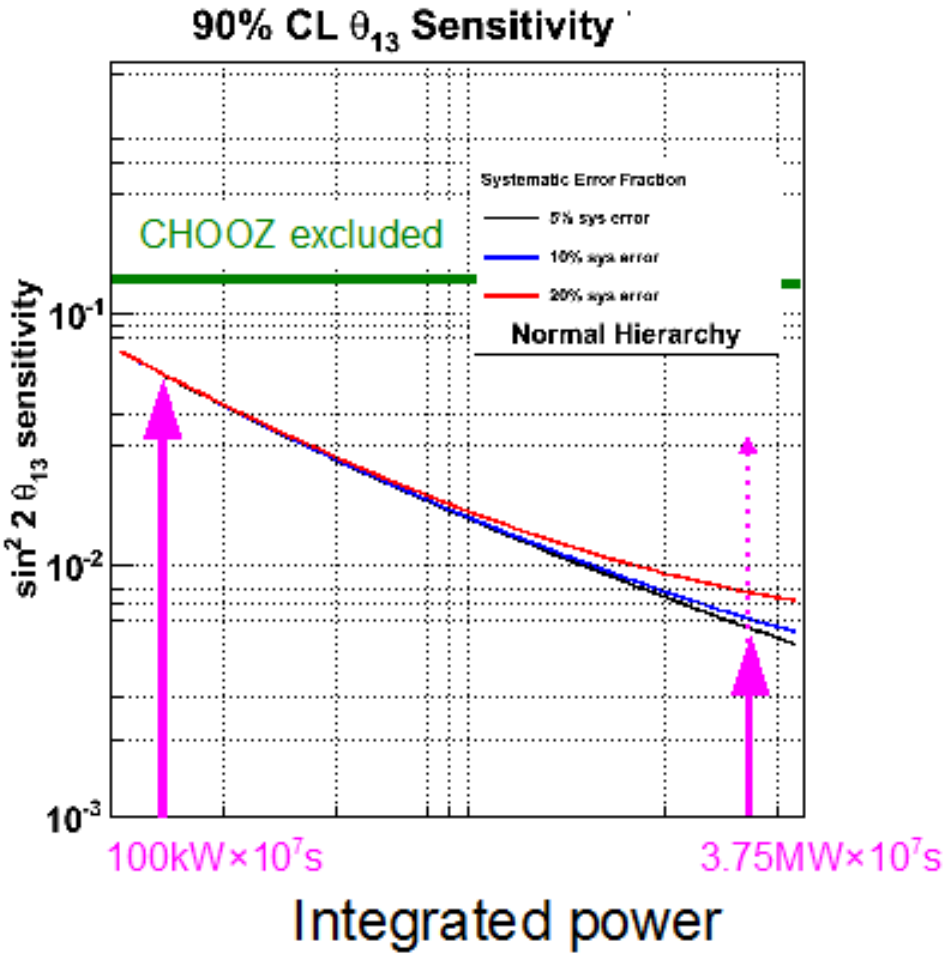
×2.1

| Current [kA] | Peak [pC] | Sigma [cm] |
|---|---|---|
| 320 | 1551 | 82 |
| 250 | 467 | 95 |
| 0 | 219 | 109 |

| Current [kA] | Peak [pC] | Sigma [cm] |
|---|---|---|
| 320 | 38.5 | 90 |
| 250 | 13.2 | 103 |
| 0 | 6.3 | 125 |

# 3. Prospect of $\theta_{13}$ search

- Aiming to search $\theta_{13}$ with better sensitivity than CHOOZ using data of 2010 physics run with 100kW × $10^7$ s operation.
- The goal is to discover $\theta_{13}$ with 3.75MW × $10^7$ s physics run. (3.75MW × $10^7$ s = 8×$10^{21}$ POT@30GeV)



# 4. Summary

- T2K is an accelerator based long base line neutrino oscillation experiment aiming to conclude neutrino mixing.
  - Discovery of $\nu_e$ appearance
  - Precise measurement of $\nu_\mu$ disappearance
- Neutrino facility started operation from April 2009.
  - Functionality of the facility was confirmed.
  - Neutrino events were observed in the near detector.
- Preparation for physics run is progressing.
- We aim to start data taking from March of 2010 and search $\theta_{13}$ with sensitivity better than CHOOZ in 2010.
- Our goal is discovery of $\theta_{13}$ with $3.75\text{MW} \times 10^7\text{s}$ physics run.