Queen Mary
University of London

Current Status of the T2K Experiment

Ryan Terri (for the T2K Collaboration)

31 May – 4 June 2010

Planck 2010, CERN

The T2K Experiment

12 countries (Canada, France, Germany, Italy, Japan, Korea, Poland, Russia, Spain, Switzerland, UK, USA)
62 institutes
~500 collaborators

Neutrino Oscillations

In 1998, Super-Kamiokande reports neutrinos have mass*, which is the first physics beyond the Standard Model
Flavor eigenstates are not the same as mass eigenstates

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

Atmospheric & accelerator | Reactor & accelerator | Solar & reactor

$$U_{\text{MNS}} = \begin{pmatrix}1 & 0 & 0\\ 0 & +c_{23} & +s_{23}\\ 0 & -s_{23} & +c_{23}\end{pmatrix}\begin{pmatrix}+c_{13} & 0 & +s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta} & 0 & +c_{13}\end{pmatrix}\begin{pmatrix}+c_{12} & +s_{12} & 0\\ -s_{12} & +c_{12} & 0\\ 0 & 0 & 1\end{pmatrix} \approx \begin{pmatrix}0.8 & 0.5 & s_{13}e^{-i\delta}\\ 0.4 & 0.6 & 0.7\\ 0.4 & 0.6 & 0.7\end{pmatrix}$$

θ_{23} = 37° ~ 53°
$\Delta m_{23}^2 \approx 2.4 \times 10^{-3}$ eV^2

θ_{13} < 10° by CHOOZ

$\theta_{12} \approx 34.4° \pm 1.3°$
$\Delta m_{12}^2 \approx 8 \times 10^{-5}$ eV^2

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

$\Delta m_{ij}^2 \equiv m_i^2 - m_j^2$

$$P\left(\nu_\alpha \overset{\alpha\neq\beta}{\rightarrow} \nu_\beta\right) \approx \sin^2(2\theta)\sin^2\left(1.267\frac{\Delta m^2 L}{E}\right)$$

$$P(\nu_\alpha \rightarrow \nu_\alpha) \approx 1 - \sin^2(2\theta)\sin^2\left(1.267\frac{\Delta m^2 L}{E}\right)$$

L [km]
E [GeV]
Δm^2 [eV^2]

2 flavor approximation

*Super-Kamiokande Collaboration, PRL **81**, 1562 (1998)

T2K Oscillation Physics Goals

Precision measurement of atmospheric neutrino oscillation parameters
- Is θ_{23} maximal?

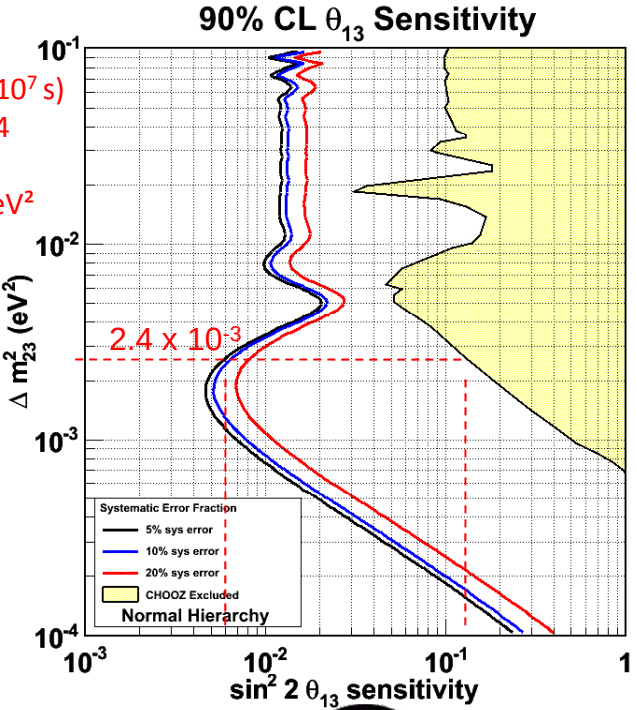
First measurement of θ_{13}
- … or at least best limit
- If we can measure θ_{13}, what is δ_{CP}?

Background constraints on sterile neutrino searches

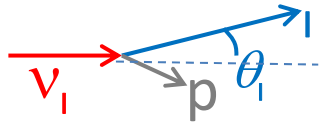
Investigate neutrino mass hierarchy

Is U_{MNS} unitary?

(0.75 MW beamx5x10^7 s)
$\sin^2 2\theta_{12}$= 0.8704
$\sin^2 2\theta_{23}$ = 1.0
Δm^2_{12} = 7.6x10-5eV^2
δ_{CP}=0

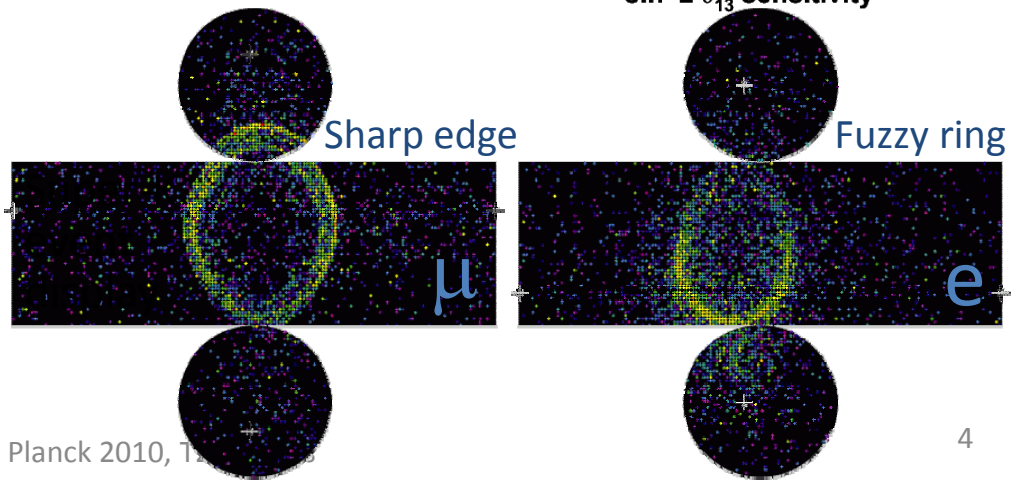


CCQE



$$E_\nu^{rec} \approx \frac{m_n E_l - m_l^2/2}{m_n - E_l + p_l \cos\theta_l}$$

Select CCQE-enhanced samples: single Cherenkov ring that's muon-like for disappearance or e-like for appearance (with additional cuts for larger S/B)



J-PARC Beamline

1: 181 MeV LINAC

2: 3 GeV Synchrotron (RCS)

6: 30 GeV Main Ring

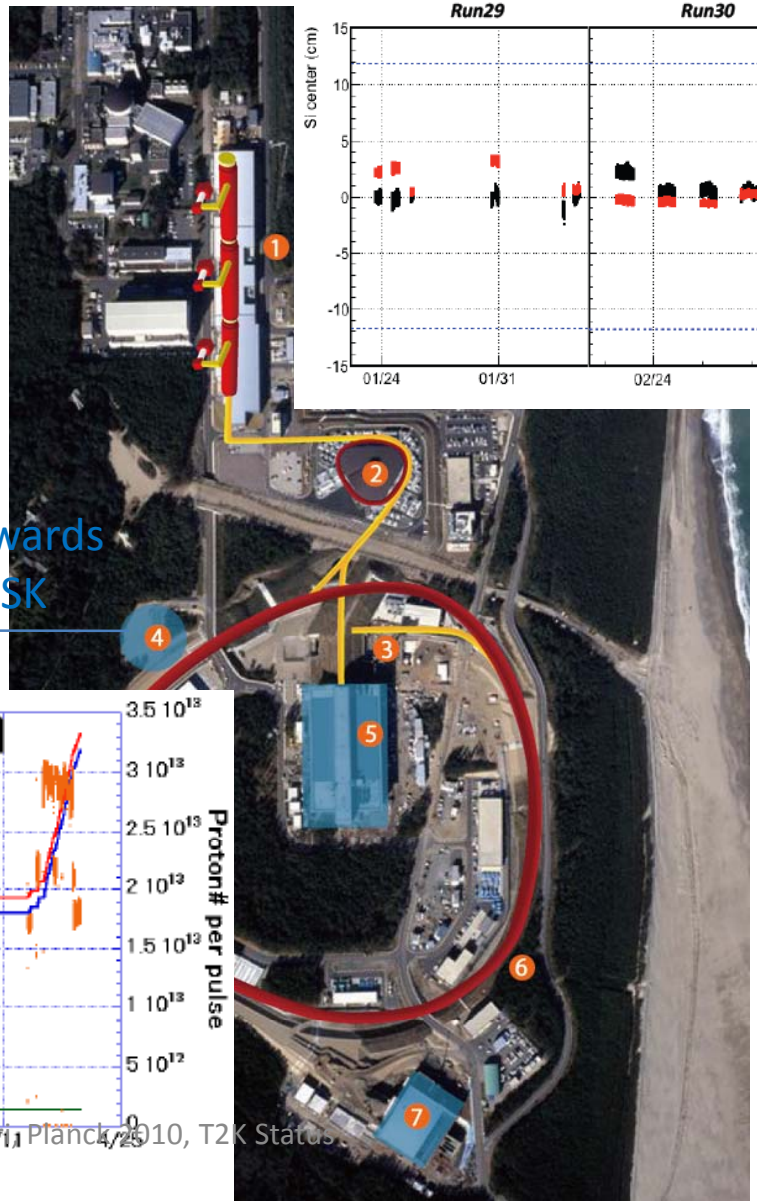
- 6 bunches w/ 581 ns between each bunch
- 0.3 Hz rep rate

3: Neutrino Beamline & Target Station

- Carbon target encased in first of 3 magnetic horns which currently operate at 250 kA
- Muon monitor at end of 110 m decay volume

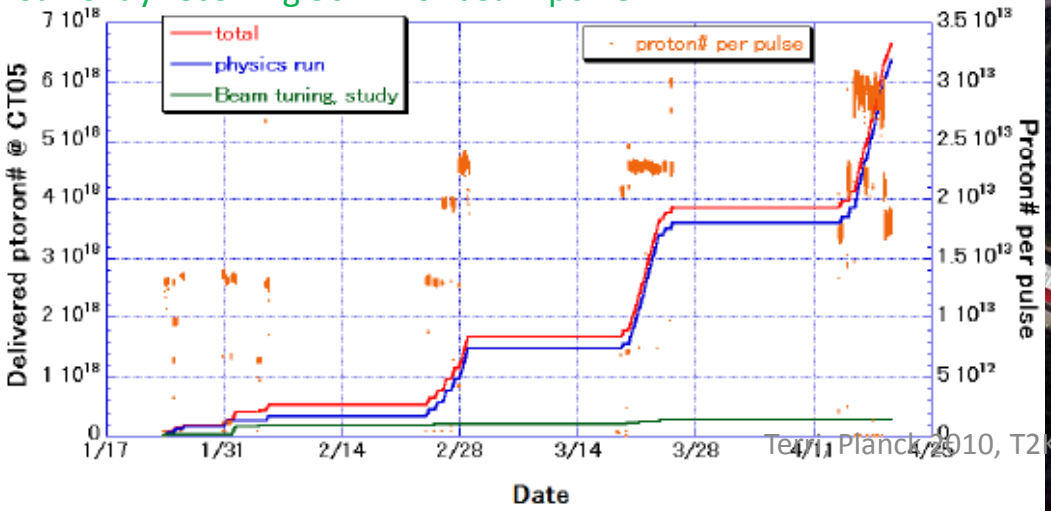
4: The Pit

- 280 m downstream of target
- Houses on- and off-axis Near Detectors



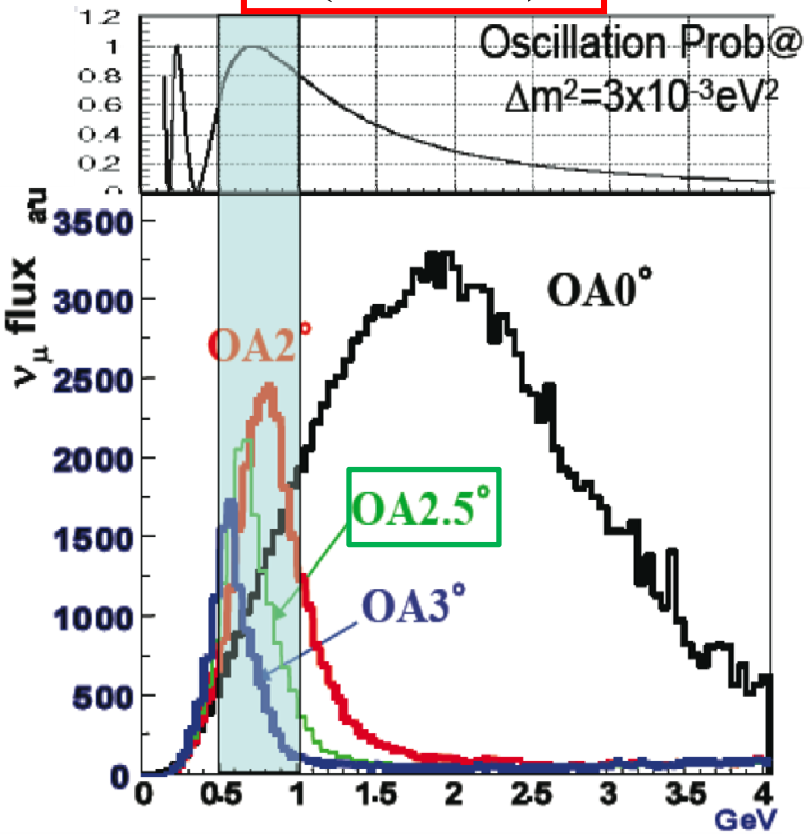
within 1 mrad of 2.5^0 off-axis angle

Currently receiving 50 kW of beam power

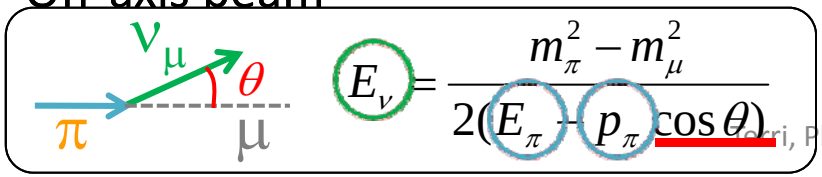


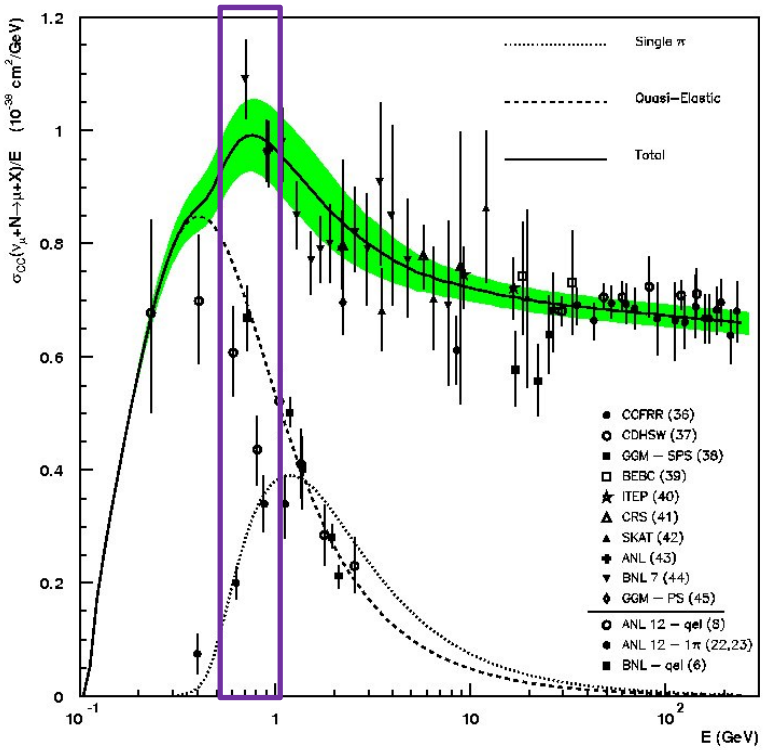
Neutrino Beam Flux

$$\sin^2\left(1.267\frac{\Delta m^2 L}{E}\right)\approx 1$$



Off-axis beam





Off-axis angle of 2.5°

Beam closer to being monoenergetic

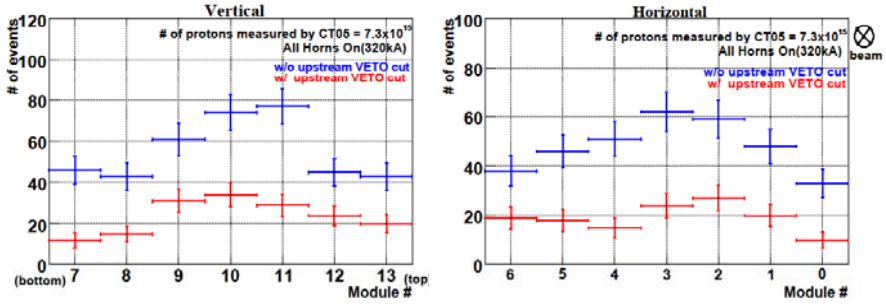
Suppressed high energy tail

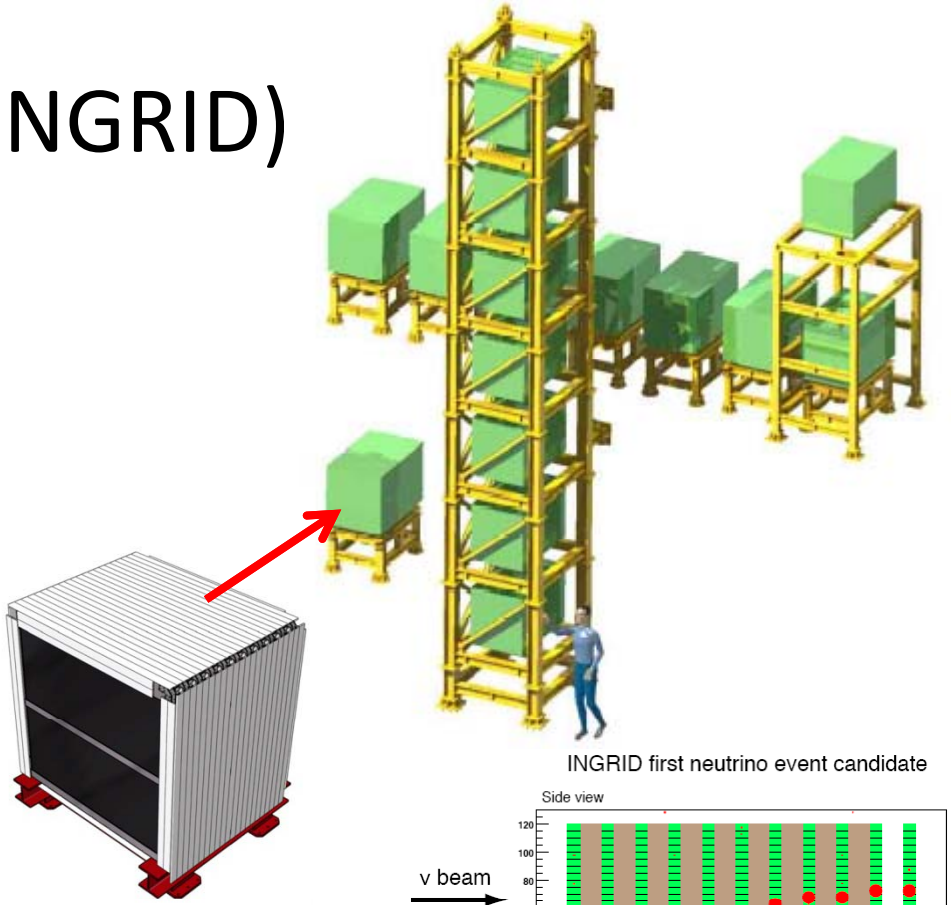
Higher intensity in region of interest

Fewer non-CCQE interactions

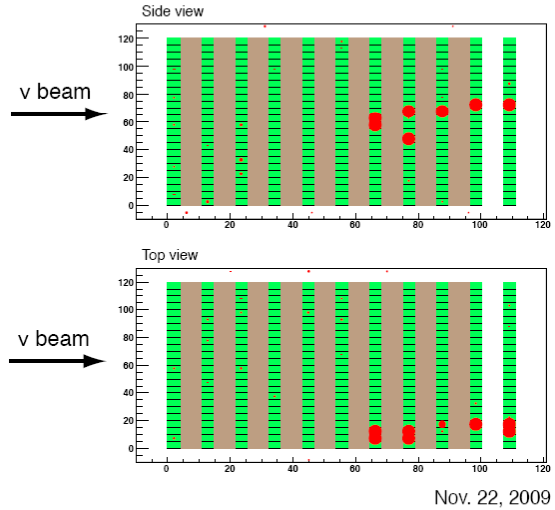
On-Axis Near Detector (INGRID)

Monitors beam direction and flux with
~1-day statistics using beam profile



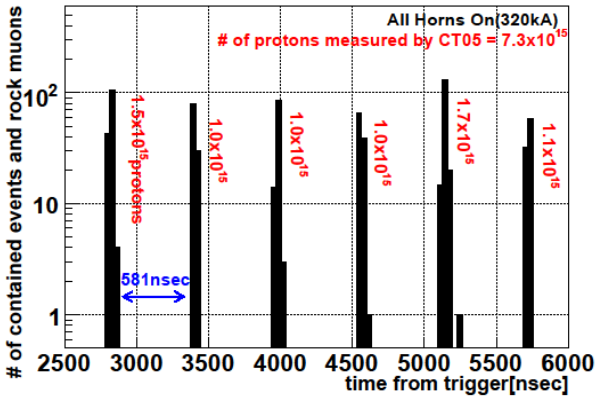


INGRID first neutrino event candidate

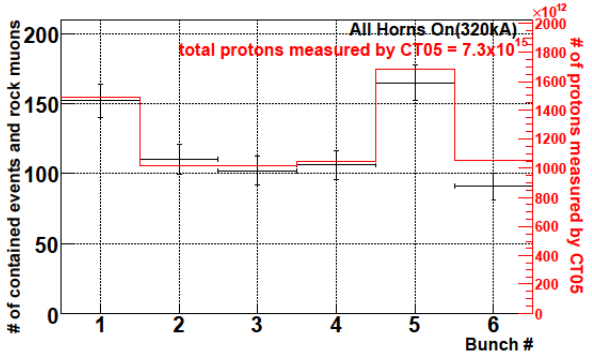


Nov. 22, 2009

MR Shot #19655
T2K Spill# 241792

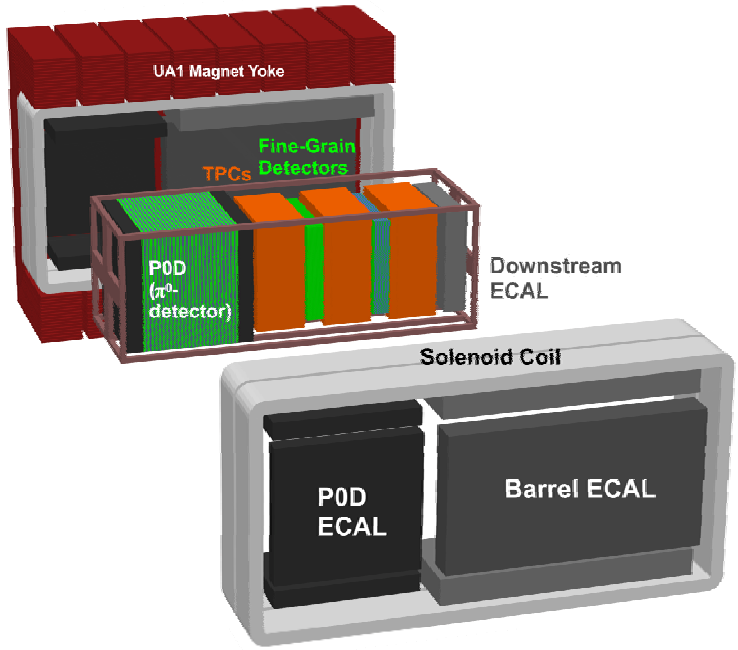


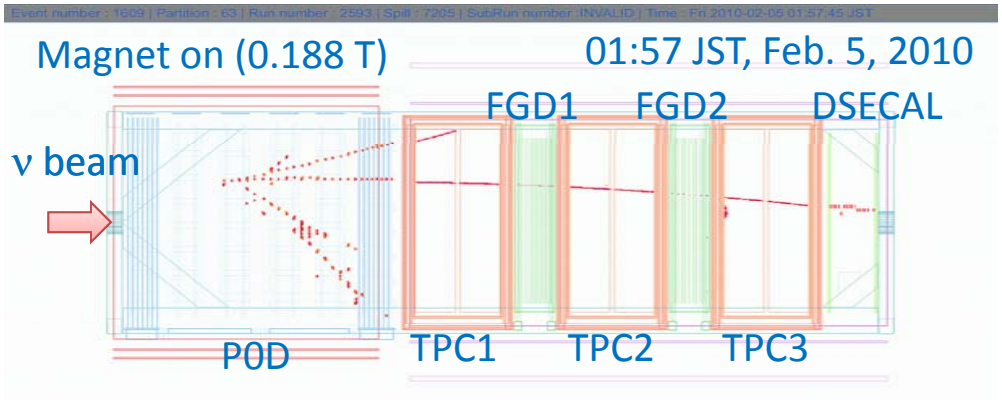
Can see beam bunch structure

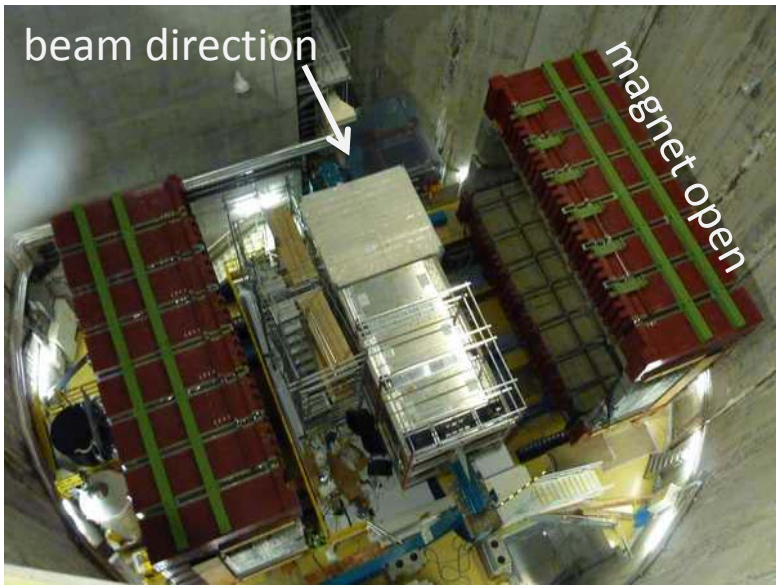


The Off-Axis Detector

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

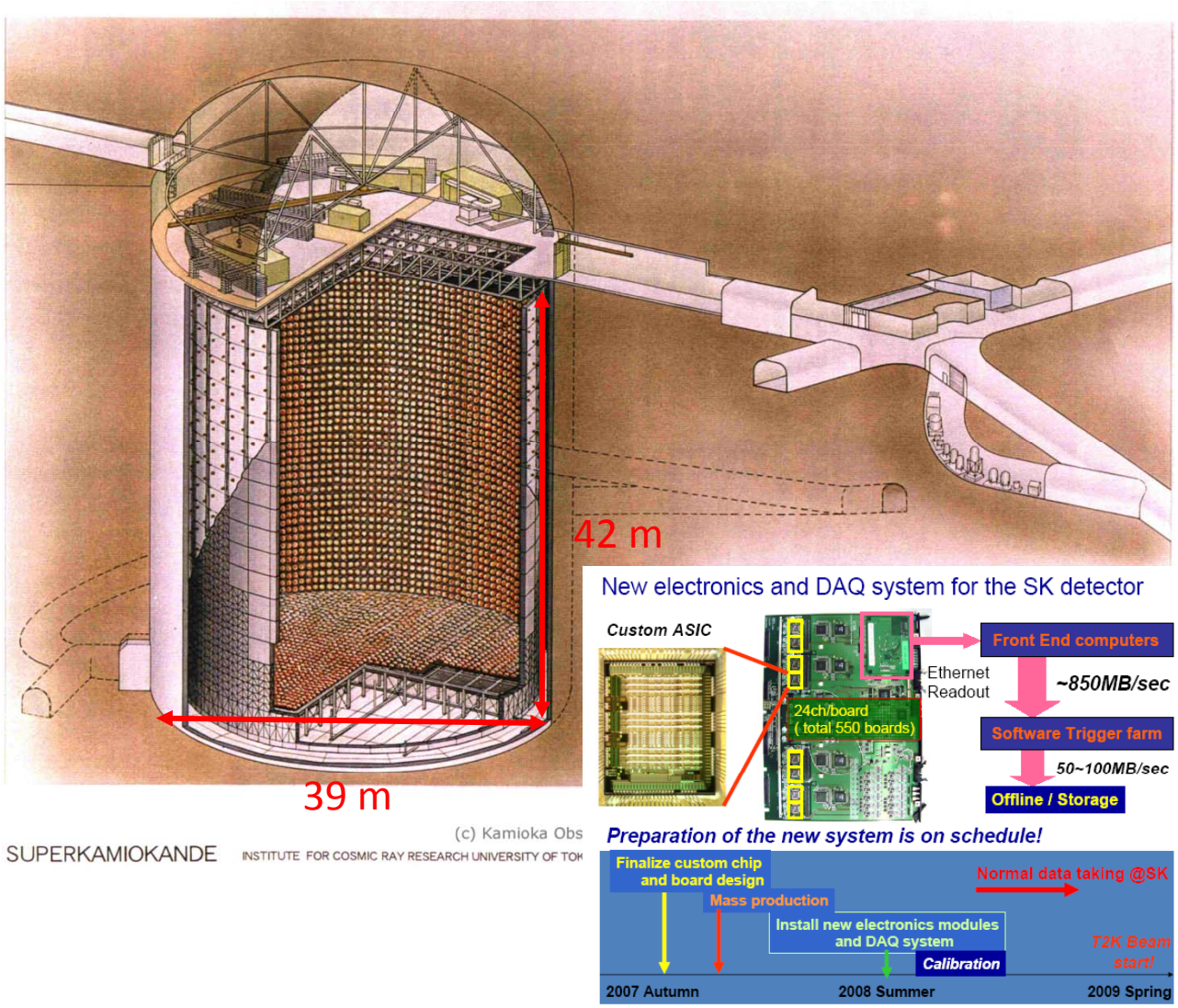






Still undergoing calibration
Rest of ECAL to be installed this summer

Super-Kamiokande



50 kton water Cherenkov detector

Located in the Japanese Alps in Western Japan

22.5 kton fiducial volume

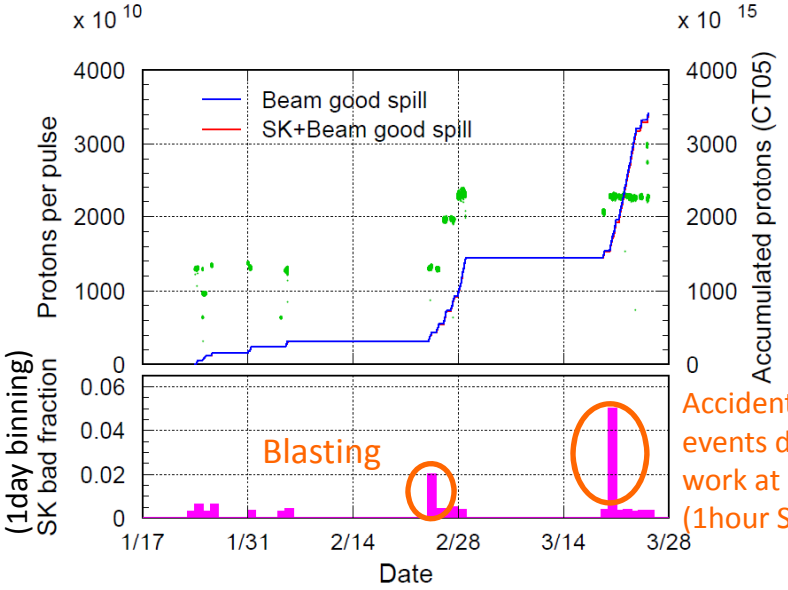
11129 20" Inner Detector (ID) PMTs , 39% photo-coverage

1885 8" Outer Detector (OD) PMTs w/ WLS Plates

New electronics installed and taking data successfully

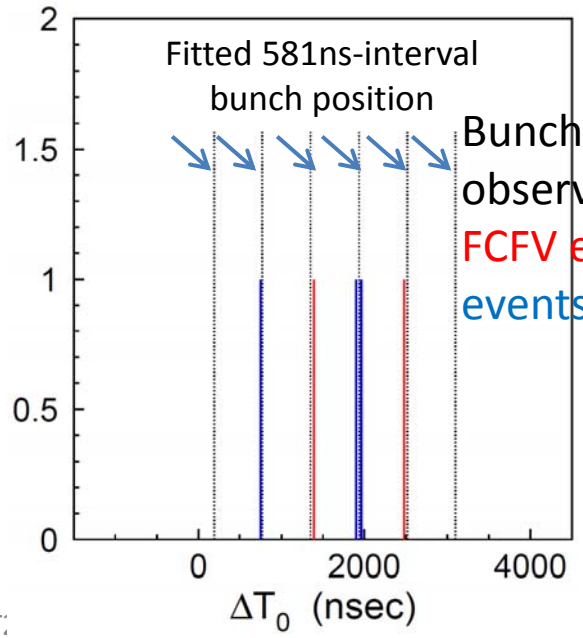
Current # of Candidate Events for T2K Oscillation Analyses

For 3.4×10^{18} POT:	Class	R29	R30	R30	Total	Exp. BG
	T2K-FC	0	1	1	**2**	6.8e-03
	T2K-FC + FV + $E_{visible}$>30 MeV	0	1	1	**2**	1.9e-04
Event rate cross check:	T2K-OD	1	4	5	10	6.6



Accidental flash events due to work at SK tank. (1hour SK dead)

>99% livetime



Bunch structure is observed for SK FCFV events and OD events

Summary/Outlook

- T2K is a long-baseline neutrino oscillation experiment
  - Will make precision measurement of the atmospheric neutrino oscillation parameters
  - From January 2010, started $\nu_\mu \rightarrow \nu_e$ search
  - Use these measurements as stepping stone for more exotic neutrino model searches
- T2K is currently collecting data and will through June
  - Will resume in Fall 2010
  - Beam now achieves over 50 kW of power
    - Try continuous operation at >100 kW after summer shutdown
  - Near Detector is seeing events consistent with beam
    - Some commissioning still to be done for off-axis detector
  - SK has seen its first potential events for an oscillation analysis
- Initial results expected later on this year

A Possible Interpretation of Physics Beyond the Standard Model:

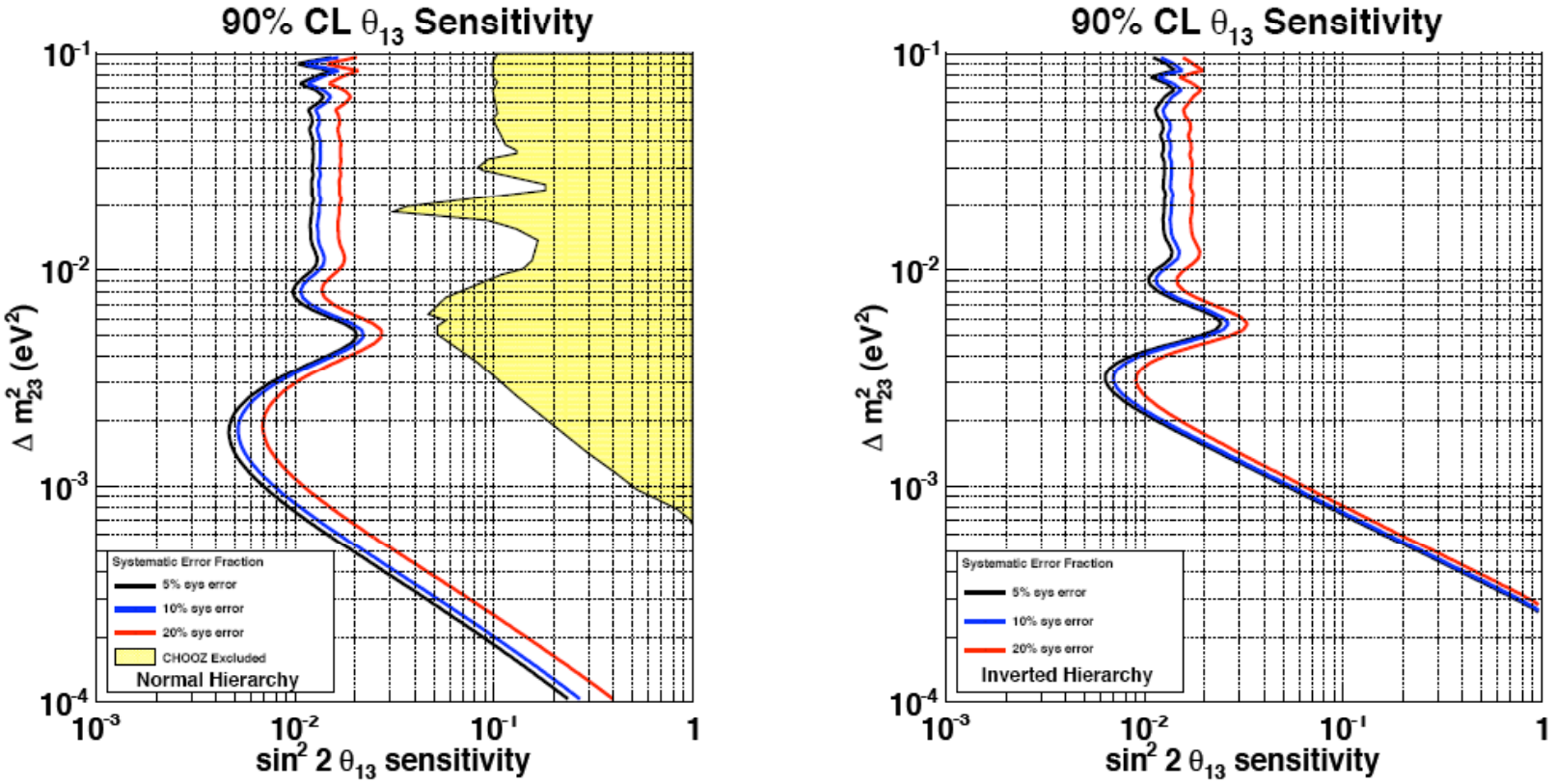
"There is a theory which states that if ever anyone discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable.

There is another theory which states that this has already happened."

-Douglas Adams, *Hitchhiker's Guide to the Galaxy*

SUPPLEMENTARY SLIDES

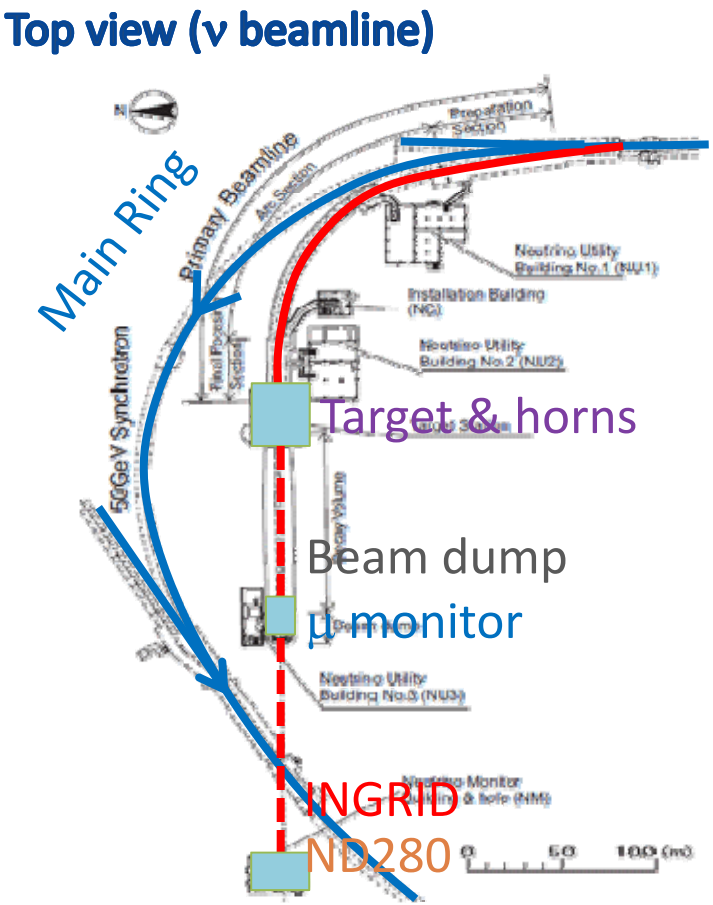
T2K Sensitivity to θ_{13} after 5 years of nominal data taking



0.75 MW beam x 5 yr x 10^7 s/yr, $\sin^2 2\theta_{12}$= 0.8704, $\sin^2 2\theta_{23}$ = 1.0,
Δm^2_{12} = 7.6x10-5eV², δ_{CP}=0

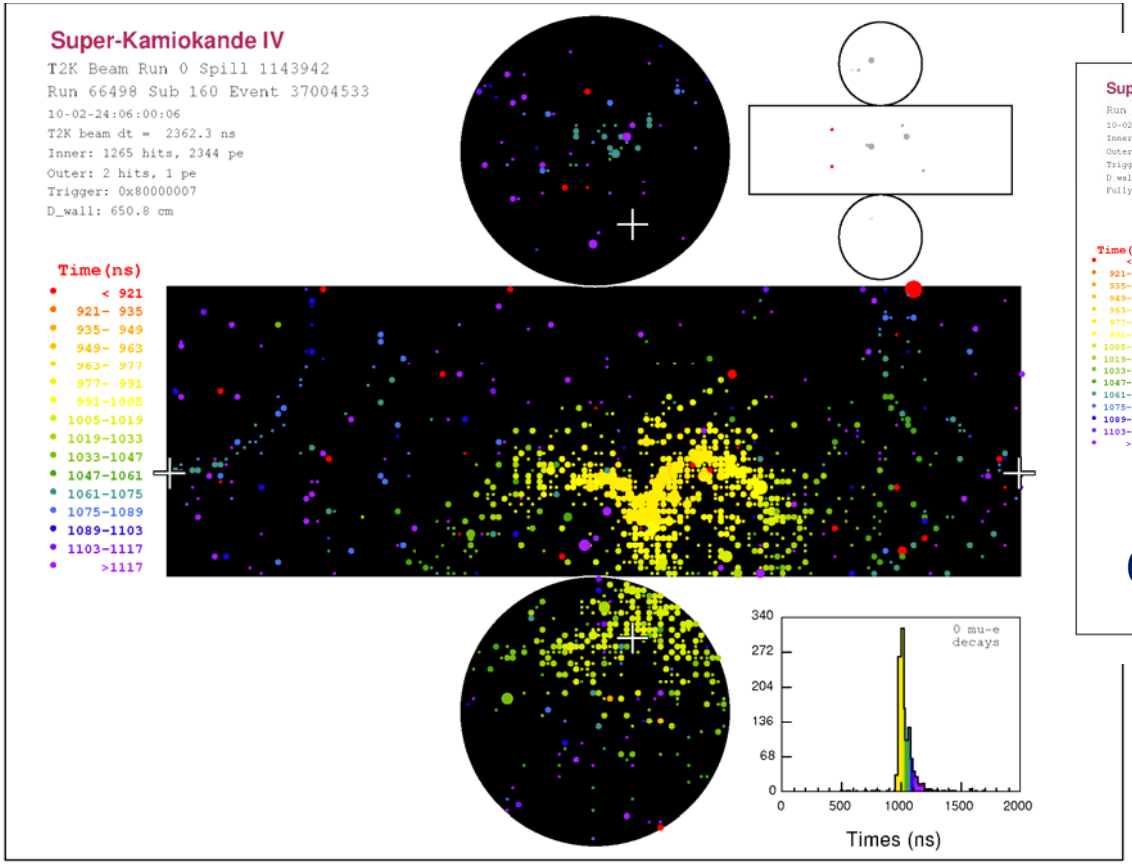
Neutrino Beamline & Planned Upgrades for Increased Intensity

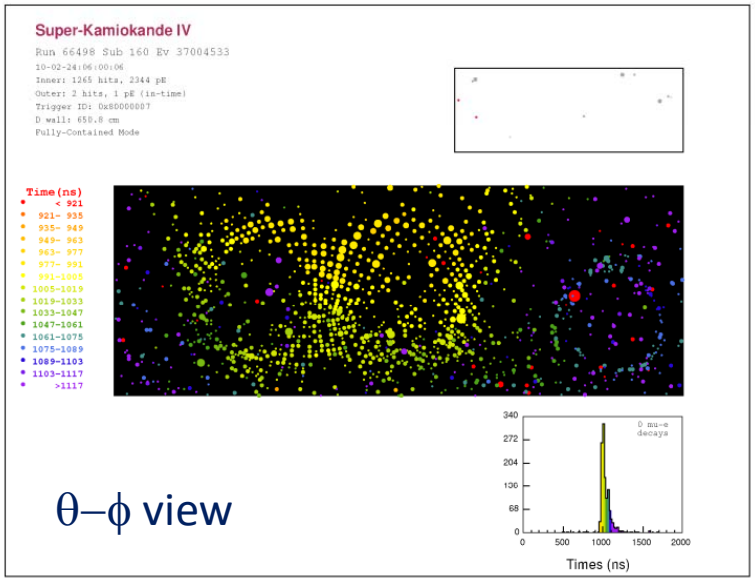
- New kicker magnet to be installed
- Increase # of bunches in proton beam from 6 to 8
- Increase rep rate & # of protons/bunch



First Event Candidate At Super-K

Feb. 24, 2010





Fully Contained, in the fiducial volume (FCFV)
2 showering rings:
invariant mass = 133 MeV/c^2
momentum = 148 MeV/c

SK sub-GeV Decay Electron Detection Efficiency

SK-IV data

SK-III data