T2K experiment: status, progress, and plans

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on behalf of the T2K collaboration

The 11th Int. Workshop on Tau Lepton Physics
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Outline

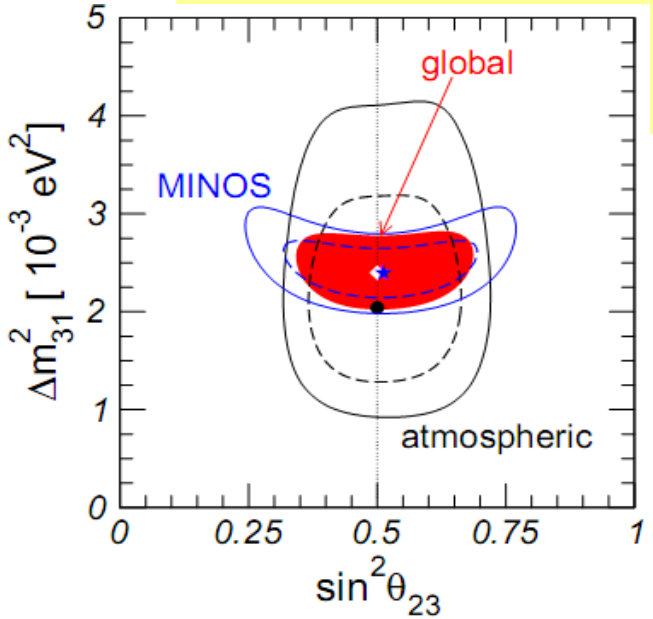
- Neutrino oscillation status and goals
- T2K experiment design and concept
- T2K experiment components
- T2K first physics run: Jan-June 2010
- Future prospects and plans

Neutrino mixing/oscillation status

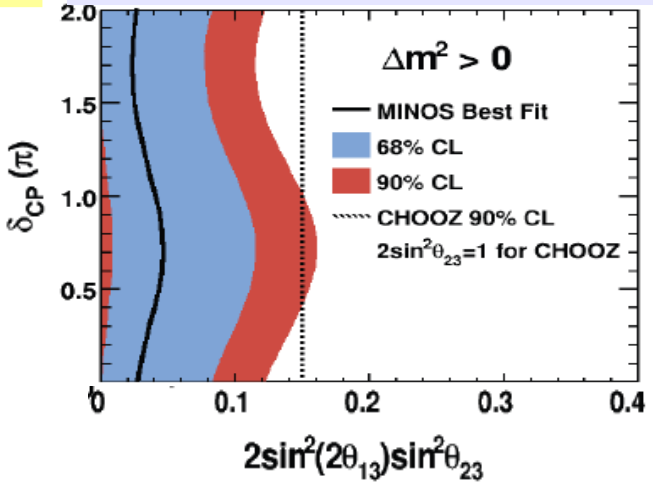
- 3-flavor mixing describes (almost) all neutrino oscillation phenomena (3 mixing angles, 2 independent mass splittings, 1 CPV phase)

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

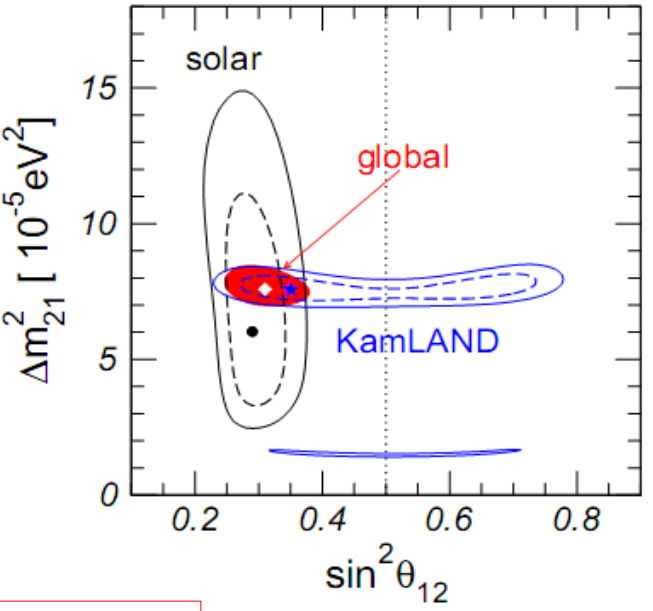
Atmospheric & accelerator:



Interference:
θ_{13} and δ_{CP} unknown
$\theta_{13} < 10^o$ (CHOOZ/MINOS)



Solar & reactor:



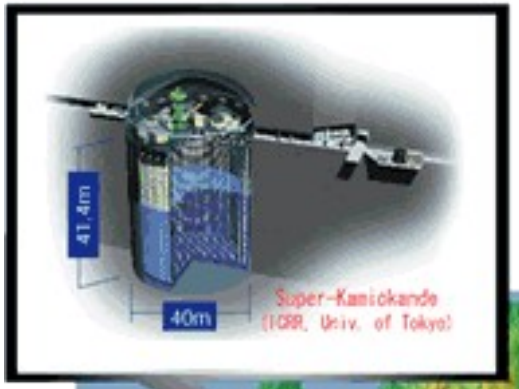
T. Schwetz, M. Tortola, J.W.F. Valle, arXiv:0808.2016v3 (11 Feb 2010)

Next generation experiments:

- measure θ_{13} and δ_{CP} (if $\theta_{13} \neq 0$)
- mass hierarchy ($\Delta m^2_{23} > 0?$)
- θ_{23} maximal (45°)?

T2K (Tokai-to-Kamioka) experiment

Far detector:
SK IV (50 kton)

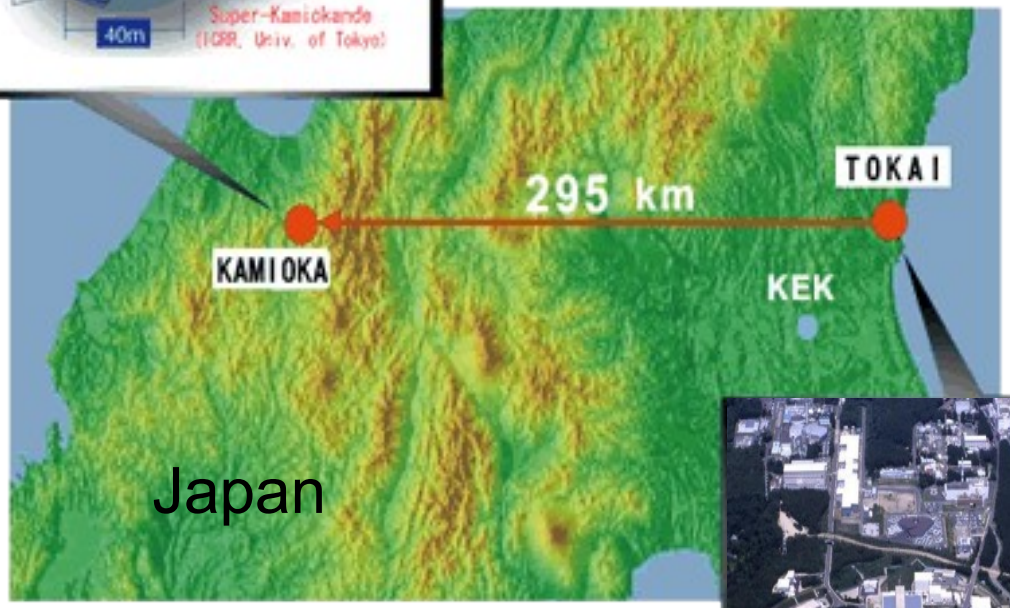


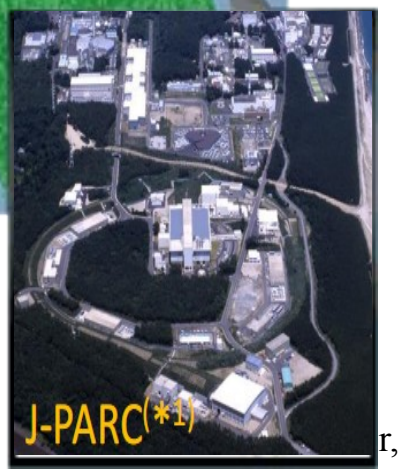
Main objectives:

- Measure/improve limit on θ_{13} ($\nu_\mu \rightarrow \nu_e$ appearance)

  $\theta_{13} \neq 0$ would allow to explore CPV in leptonic sector

- Improve measurement of Δm^2_{23} and θ_{23} ($\nu_\mu \rightarrow \nu_\mu$ disappearance)





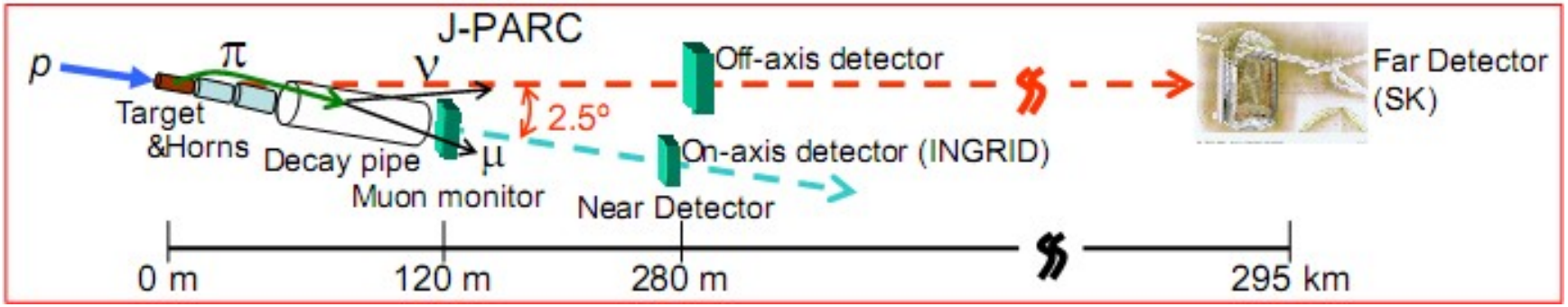
Neutrino beam originates at
J-PARC, Tokai
30-GeV 750 kW proton beam

Requirements:

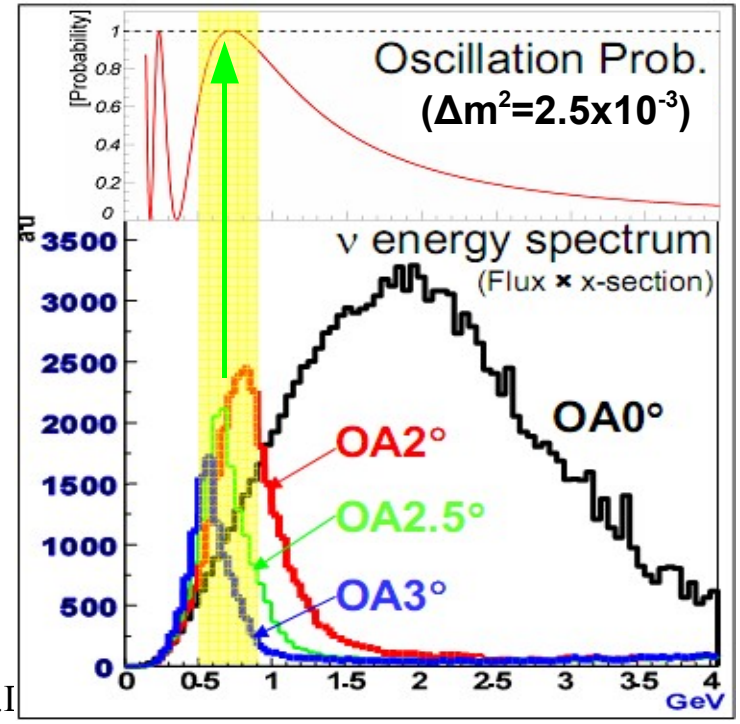
- Very intense ν beam
- Massive far detector
- Long baseline (295 km)
- Near detector (ν flux and composition near source)
- Off-axis design
  - enhance sensitivity at oscillation maximum
  - reduce intrinsic background

T2K off-axis concept

- T2K will be the first LBL *ν* experiment using an off-axis beam



- The beam is aimed 2.5° off the direction of Super-Kamiokande

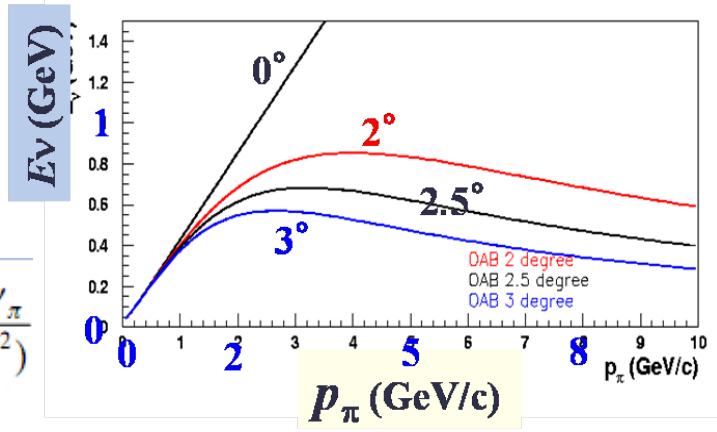


- This produces a narrow beam with peak energy (~600 MeV) tuned to first oscillation maximum ($\Delta m^2_{13} L/4E_\nu \approx \pi/2$)
- Helps to eliminate high energy tail: reduced background from non-QE interactions and NC feed down from high energy ν_μ

Two-body decay kinematics:

$$\pi^+ \rightarrow \mu^+ \nu_\mu$$

$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\vartheta)} \approx \frac{0.43 m_\pi \gamma_\pi}{(1+\gamma_\pi^2 \vartheta^2)}$$



T2K analysis strategy

- Predict ν_μ flux at near detector (ND) using beam simulation and hadron production data from target (NA61/Shine exp.)
- Compare the ND prediction to data to improve flux prediction and propagate ND constrain to far detector (FD)
- Estimate ν_μ rate (without oscillation) at far detector: N^{null}
- Compare to measured ν_e rate (ν_μ spectrum), N^{FD}, to observe oscillation and extract oscillation parameters

$$\Phi^{ND}=N^{ND}/(\sigma^{ND}\varepsilon^{ND})$$

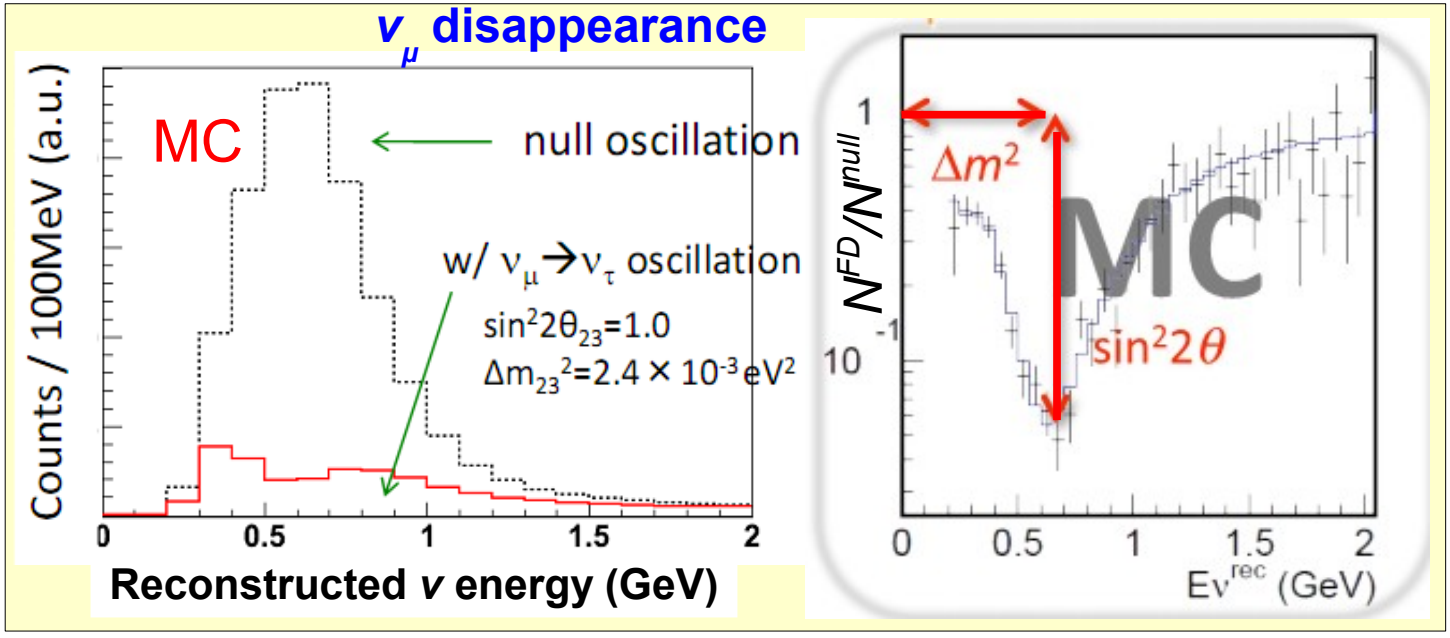
$$\Phi^{FD}=R(FD/ND)\Phi^{ND}$$

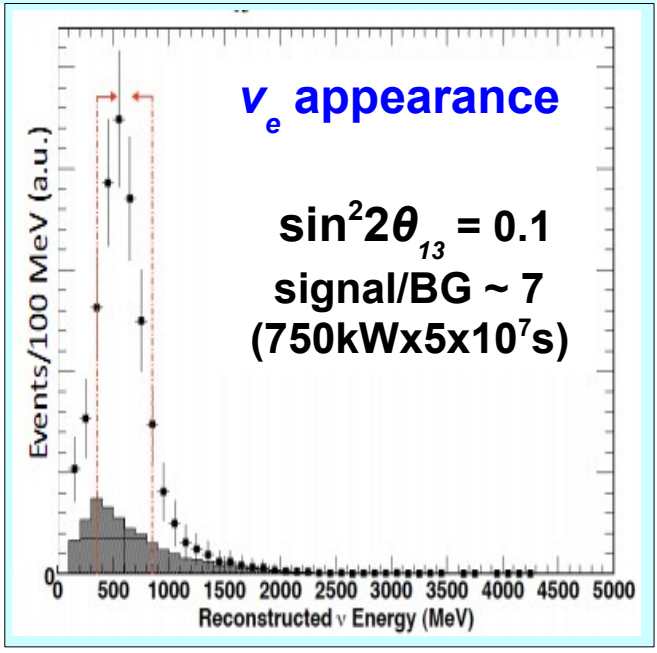
$$N^{null}=\Phi^{FD}\sigma^{FD}\varepsilon^{FD}$$

$$P(osc)=N^{FD}/N^{null}$$

$$P(\nu_\mu\rightarrow\nu_\mu) \approx 1-\sin^2 2\theta_{23}\sin^2(\Delta m^2_{23}L/4E_\nu)$$

$$P(\nu_\mu\rightarrow\nu_e) \approx \sin^2 2\theta_{13}\sin^2\theta_{23}\sin^2(\Delta m^2_{13}L/4E_\nu)$$



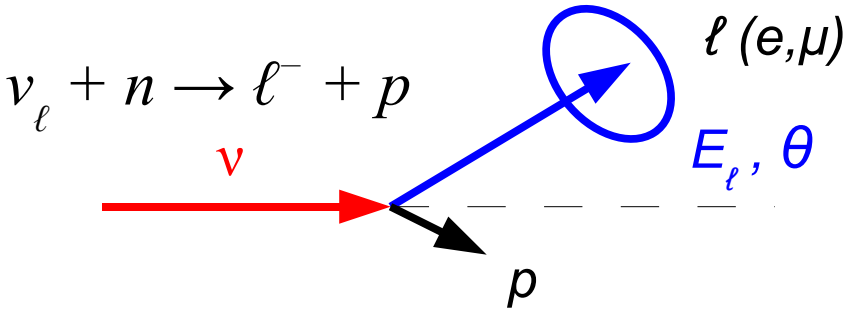


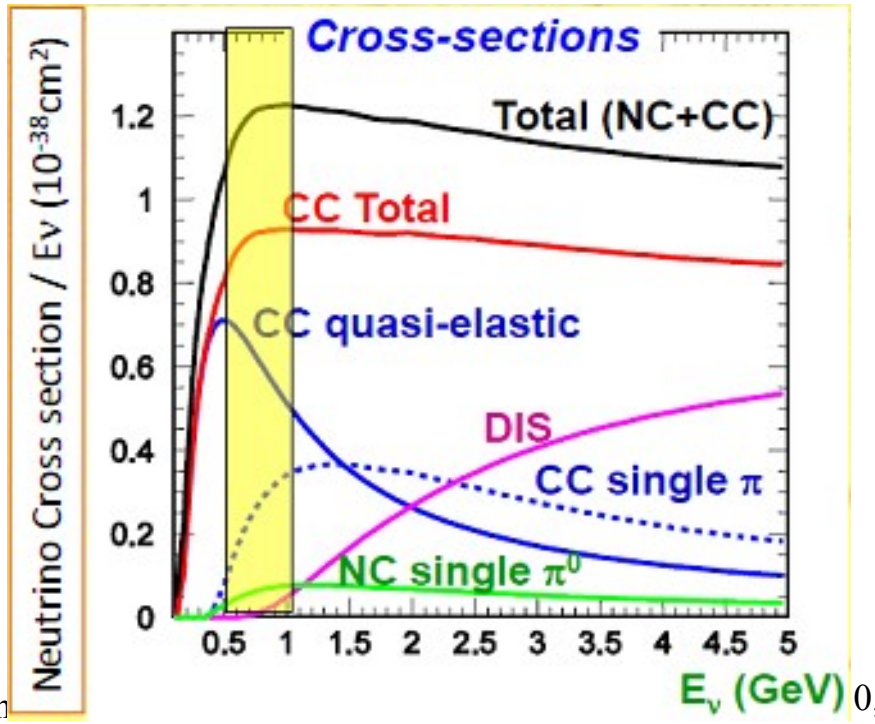
E_ν measurement

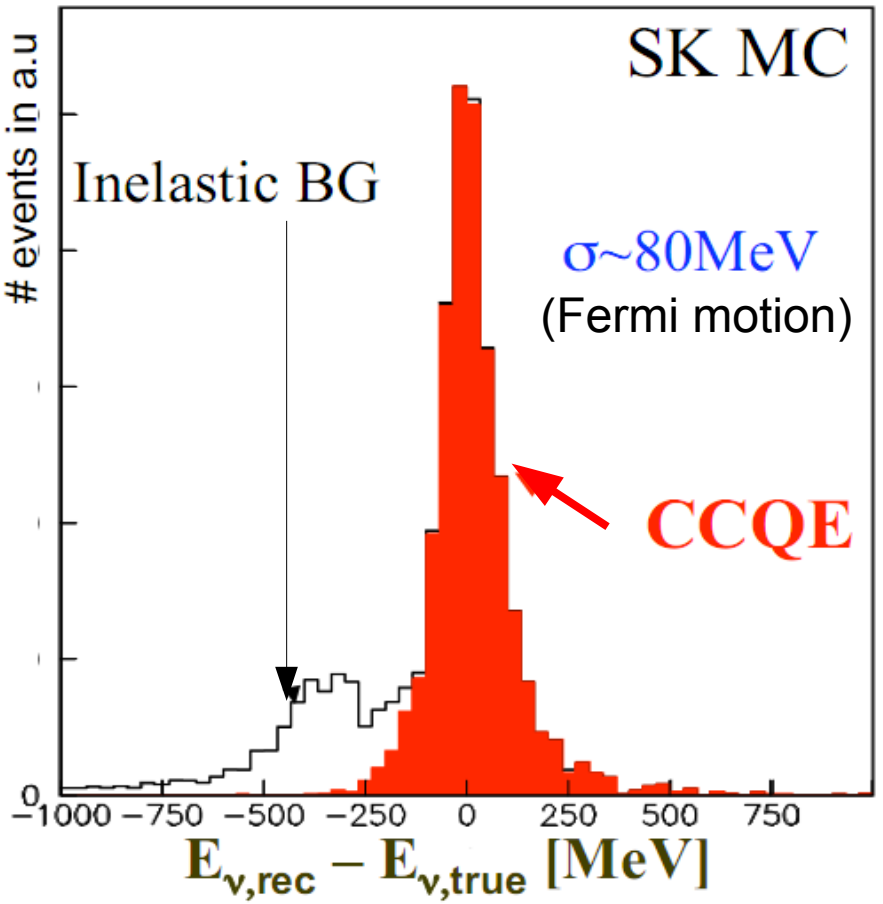
Charge Current Quasi-elastic interaction dominates at the T2K energy

- E_ν can be reconstructed from the energy and angle of the charged lepton

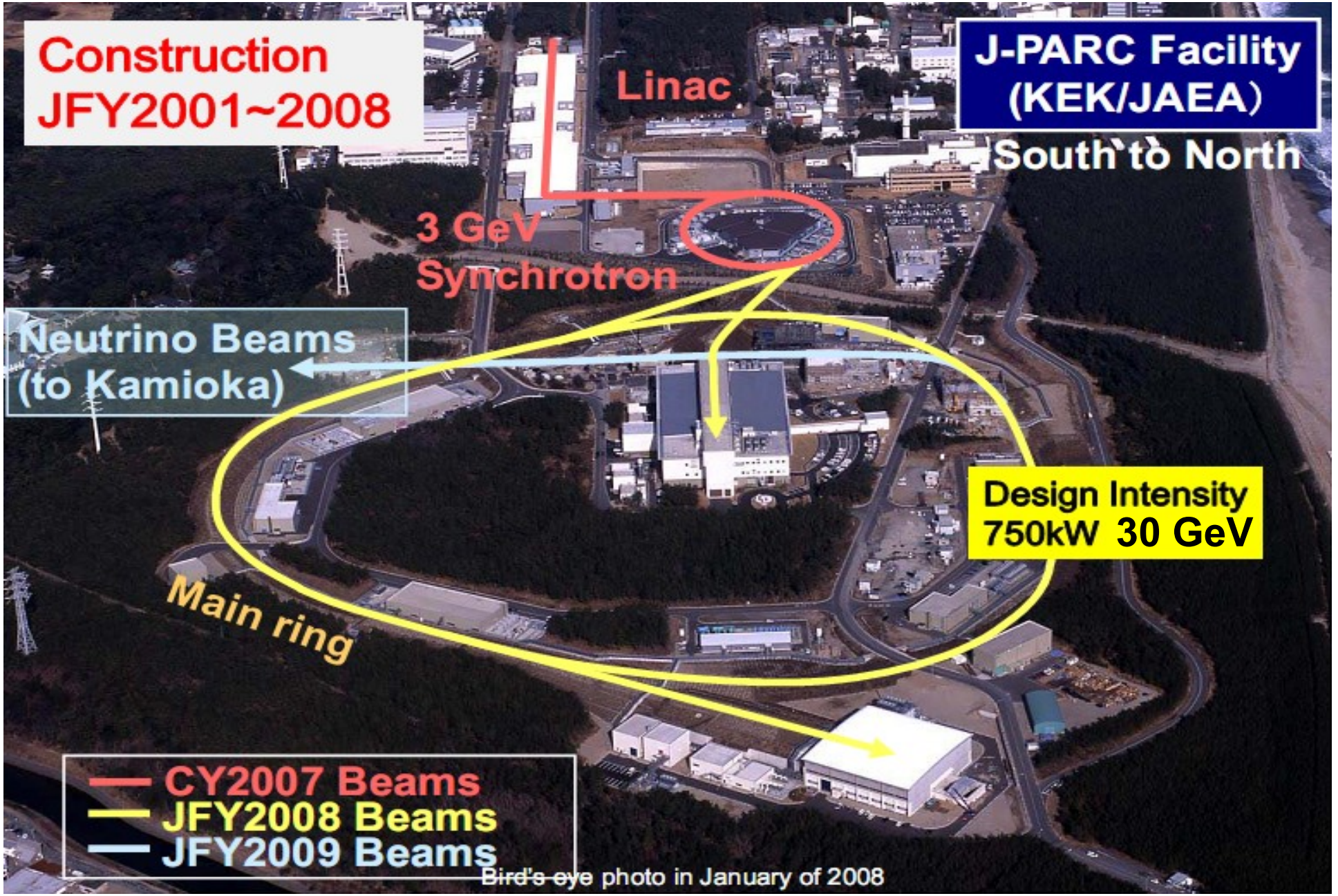
$$E_\nu = \frac{m_N E_l - m_l^2/2}{m_N - E_l + p_l \cos\theta_l}$$







Accelerator facility



Neutrino beam line

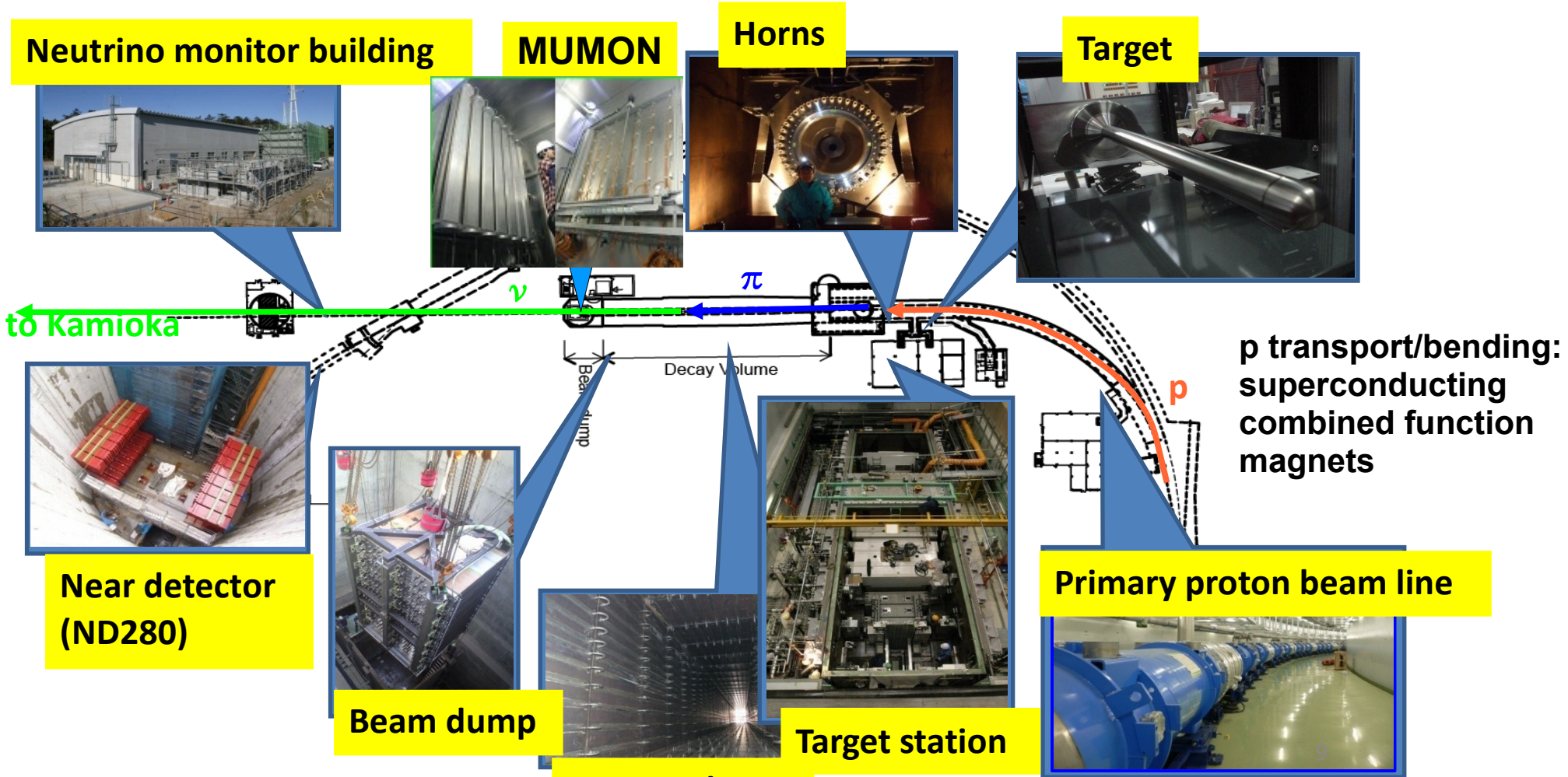
Conventional beam:

p+C → π → ν+μ

Muon monitors: Ionization chambers + SiPIN diode

3 focusing horns (250 kA)

Target: graphite (ø26mm x 90cm) in He



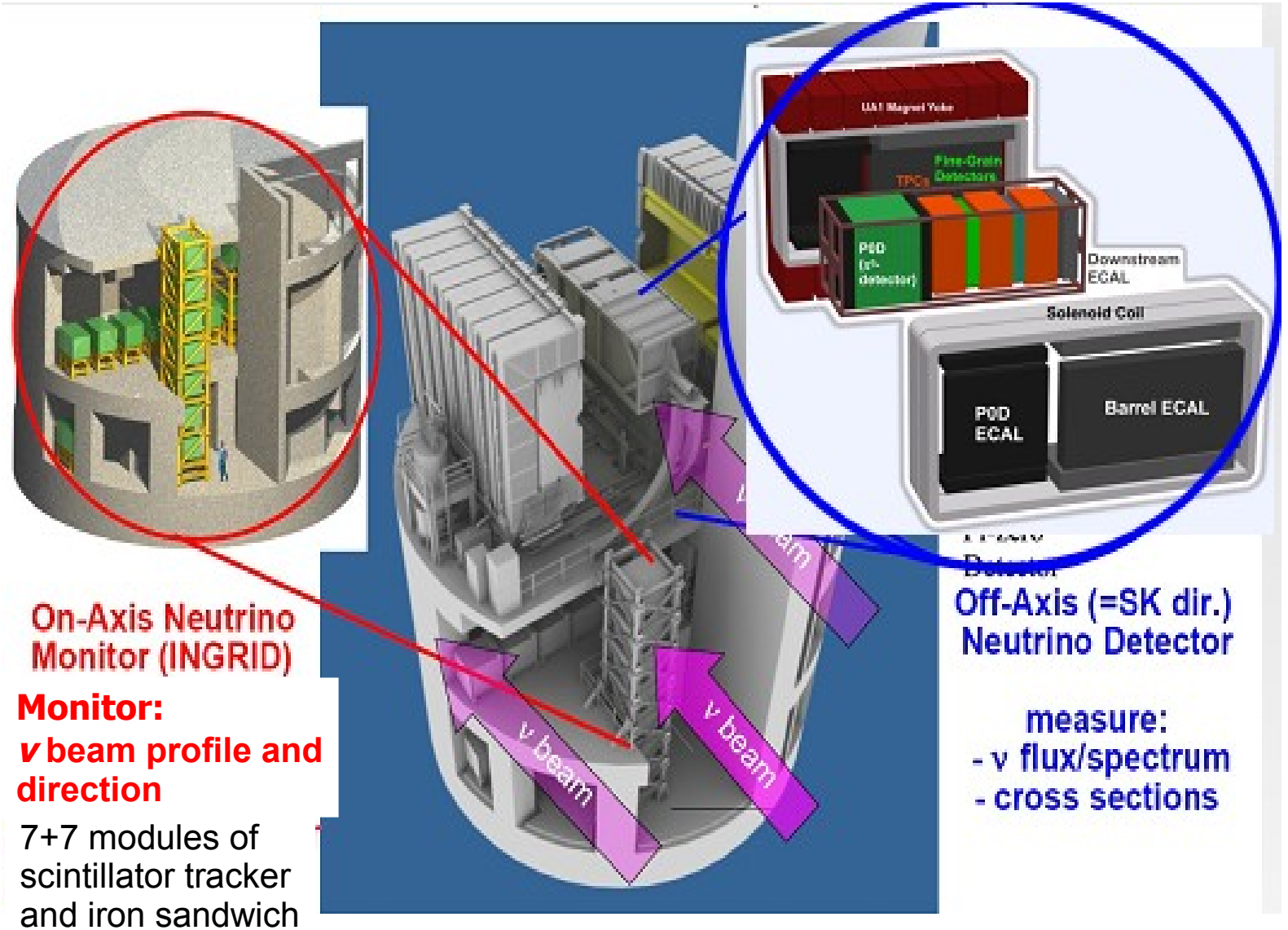
p transport/bending: superconducting combined function magnets

First beam on target:
April 23, 2009

Decay volume (110 m) He filled

Fast p extraction: 6 bunches/spill, 581 ns separation, 3.5 s spill period

Near detectors: ND280



Monitor:
ν beam profile and direction

7+7 modules of scintillator tracker and iron sandwich

Off-axis detector:

UA1 magnet: 0.2 T

P0D: pi0 detector to measure NC π^o BG

Tracker:
3 TPCs, 2 FGDs
charge partcicle
p, θ, PID (dE/dx)

ECal: EM activity

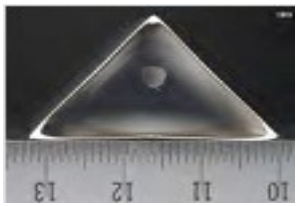
SMRD: detect side muons

Installation completed in December 2009 (barrel ECal installation this Summer)

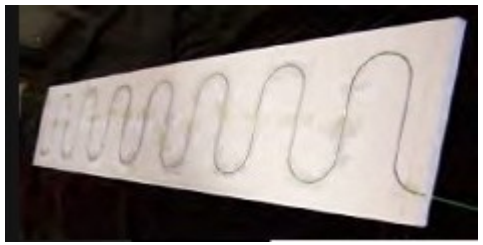
Detector commissioning finished January 2010

ND280: off-axis near detector

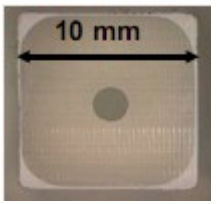
Pi0 detector (P0D): target
40 x-y scintillator planes
(~10k scint. bars)
Middle: scint+H_2O bags (11t)
Front/back: calorimeter
(veto and γ catcher)
Pb+Scint (6.4t)

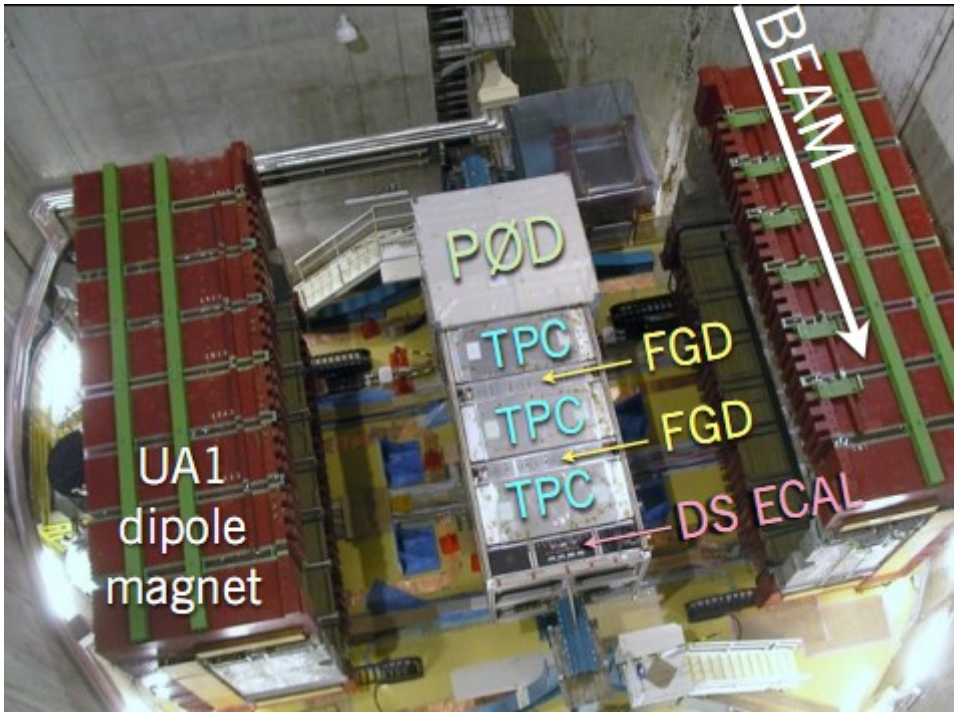


SMRD: μ range, veto
cosmic trigger
~2k scint. counters
(87x17x0.7 cm3)

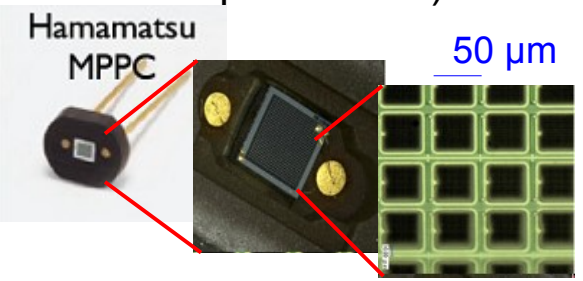


Fine Grained Detectors (FGD):
x-y scintillator planes
(~8.4k scint. bars)
+ H_2O (in FGD2)

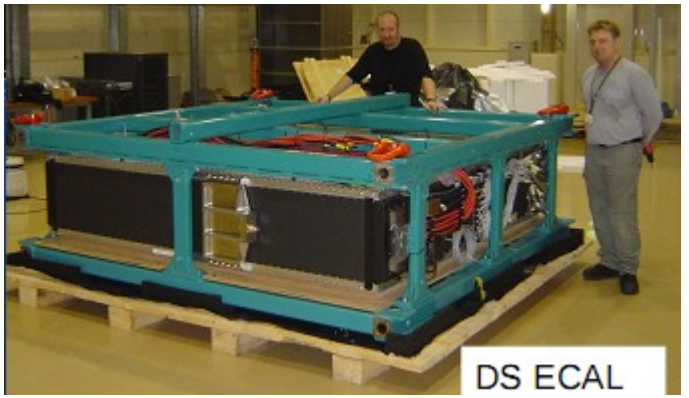




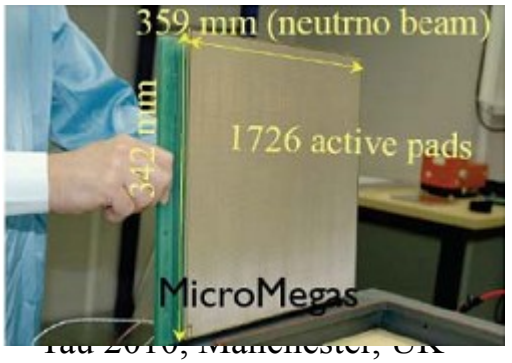
Scintillator detectors read out
via WLS fiber coupled to
Si MPPC (667 pixel
avalanche photodiode)



ECal: x-y fine grained
Pb+Scint. (4x1 cm^2)
~21k scint. bars (total)
σE/E~7.5%/√E

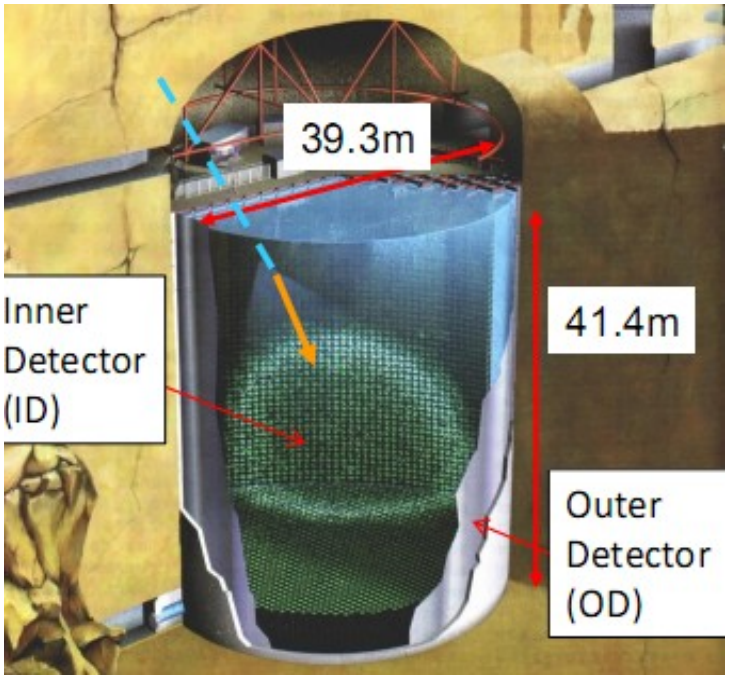


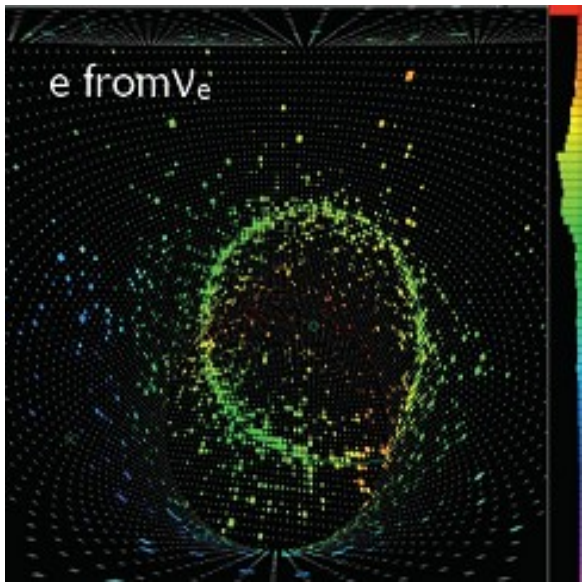
Time Projection Chambers (TPC):
wireless readout with MicroMegas
(7x10mm^2 pads) ~124k channels
5σ e/μ separation, $\sigma_p/p < 10\%$

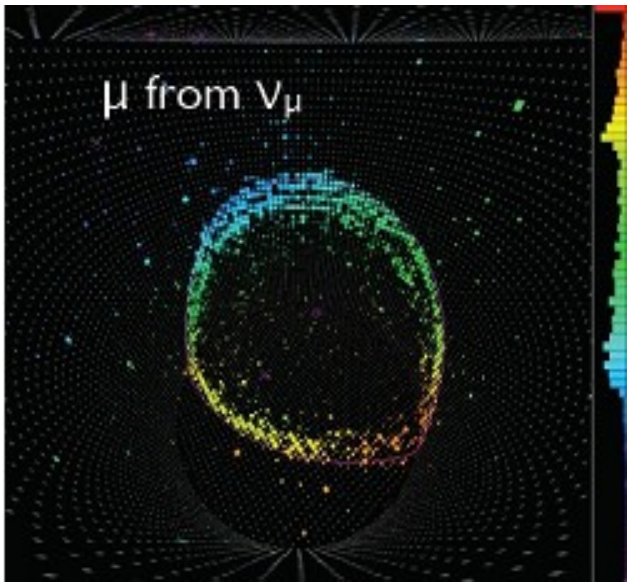


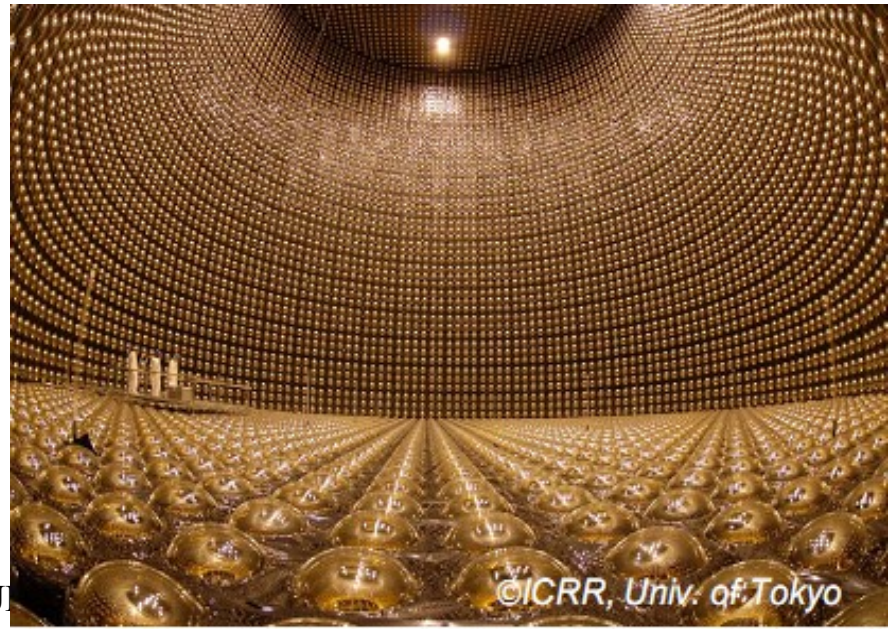
Far detector: Super Kamiokande IV

- 50 kton (22.5 kton fiducial) water Cherenkov det.
- ID: 11k 20" PMT (40% photo coverage); OD: 2k 8" veto PMT (optically isolated from ID)
- New readout electronics and DAQ (no dead time) – improved decay-electron tagging
- GPS based event timing – record events within 500 μs around spill
- Very efficient e/μ separation (~99% at 0.6 GeV)



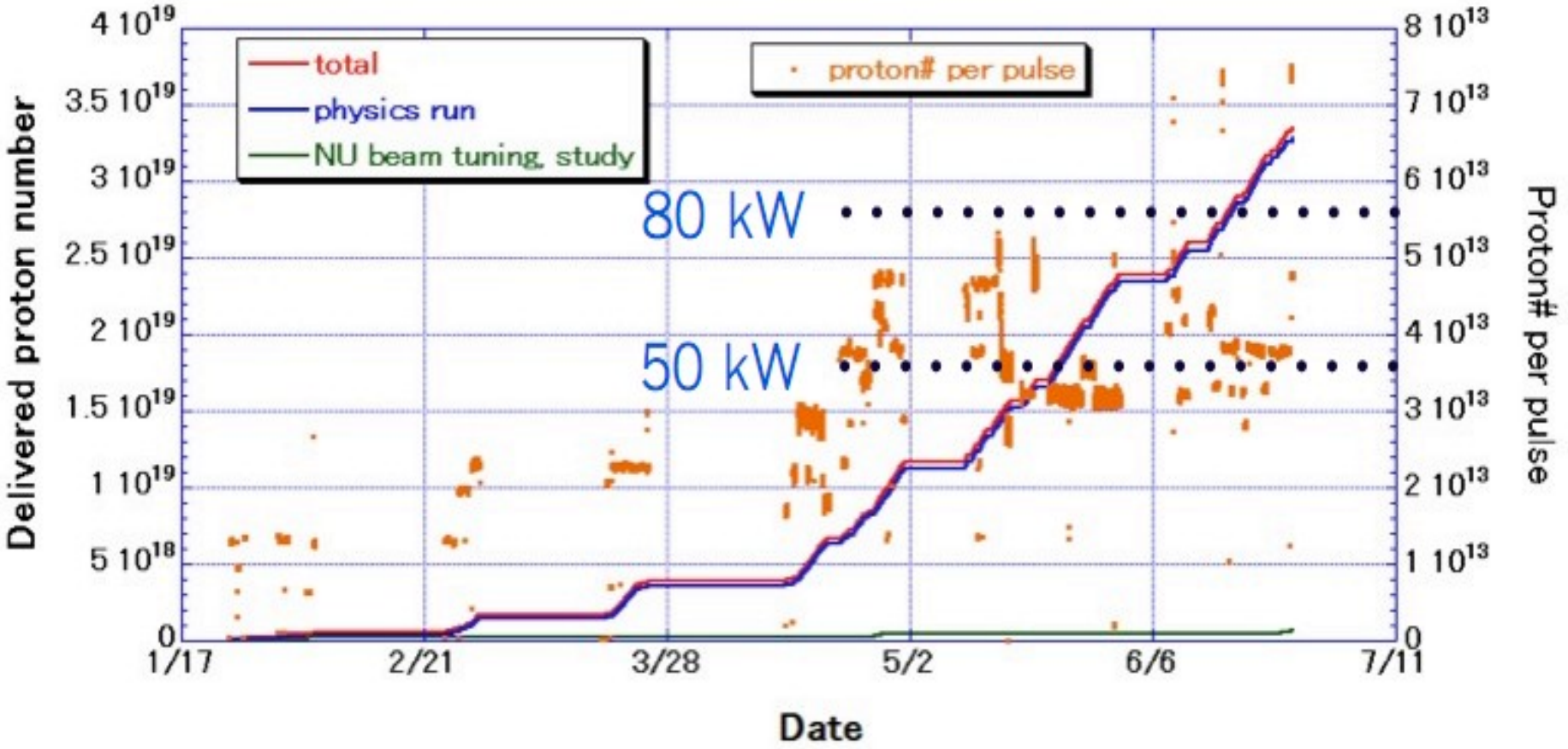






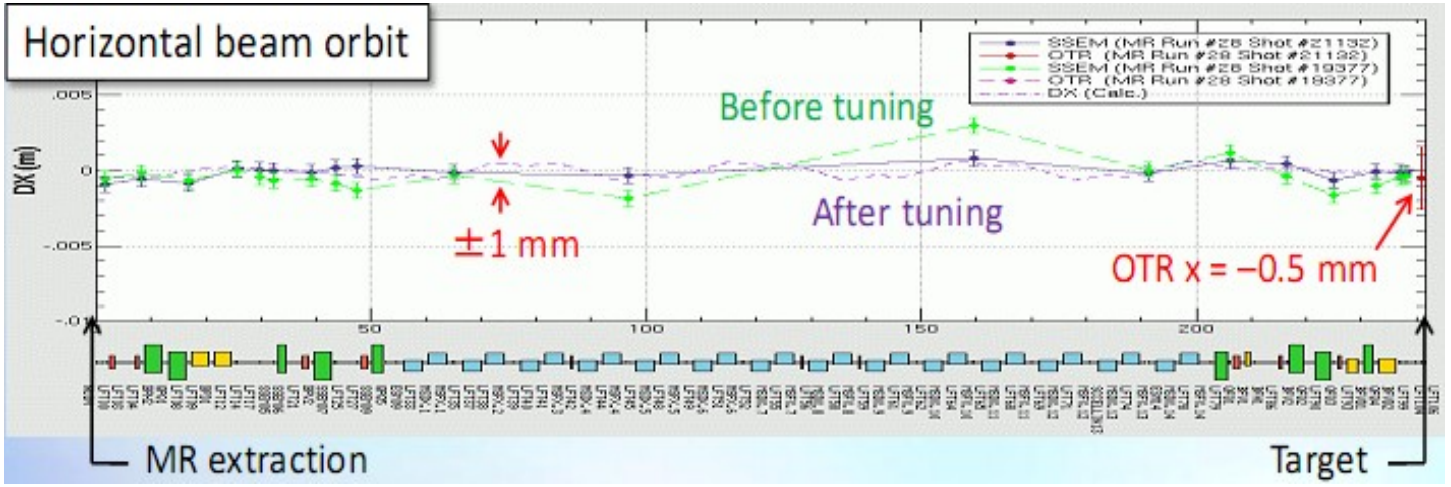
First physics run

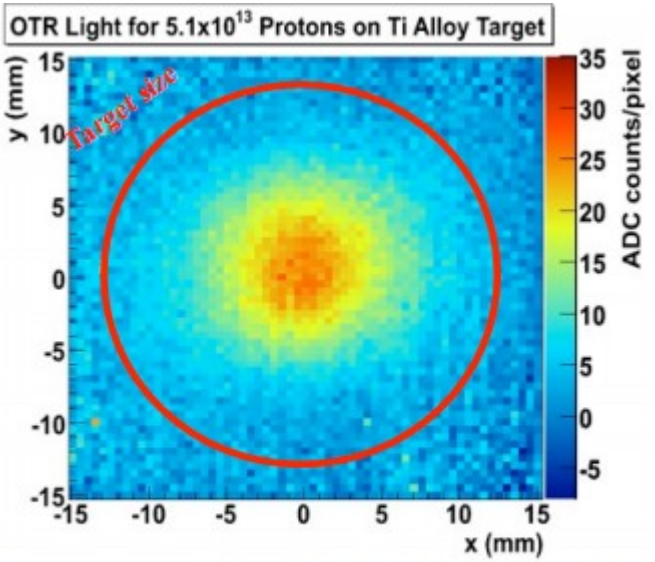
- January 23 – June 26 2010
- Beam power: ~50 kW stable running (trial shots up to 100 kW)
- Total data accumulated: 3.3×10^{19} PoT



Beam monitors

Proton beam precisely tuned (<1mm) to minimize beam loss, and control direction of secondary beam

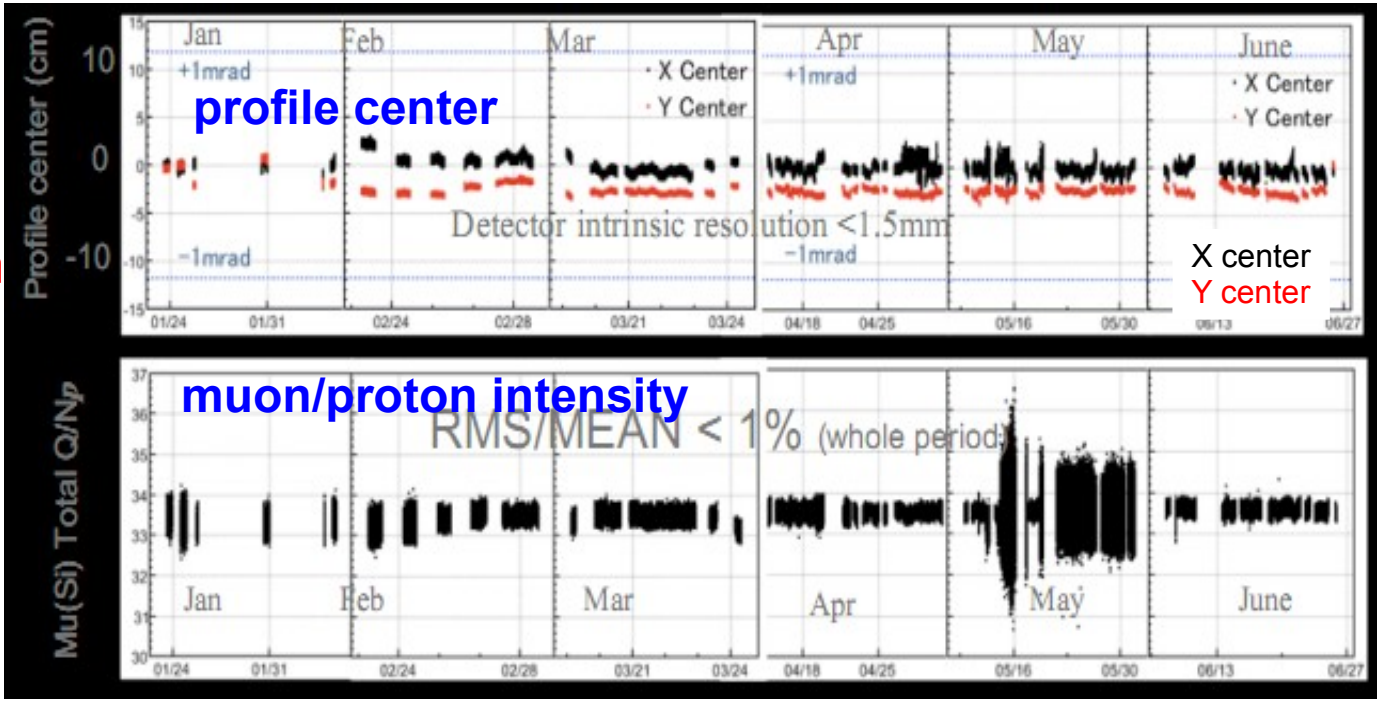




Optical transition radiation detector (OTR) immediately upstream of target:

Muon monitors (Si PIN and ionization chambers):

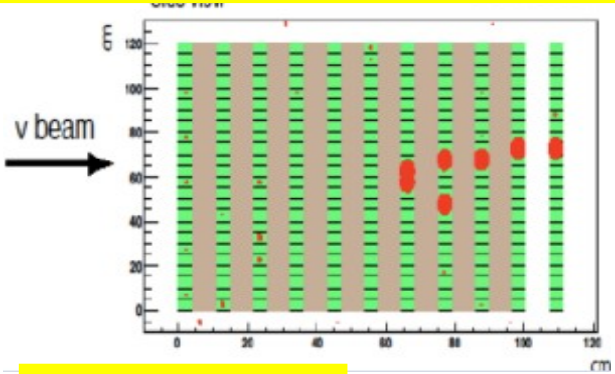
- Measure secondary beam direction and intensity spill-by-spill
- requirement: <1mrad (ΔE_ν^{peak} ~ 2%/mrad)



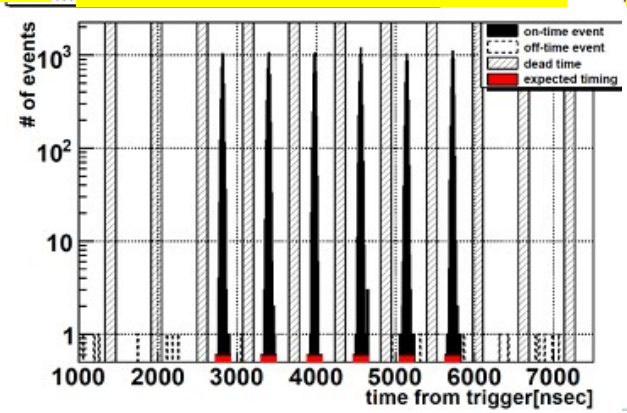
INGRID

- Measures ν-beam direction and profile using inclusive CC interaction rate in vertical and horizontal modules

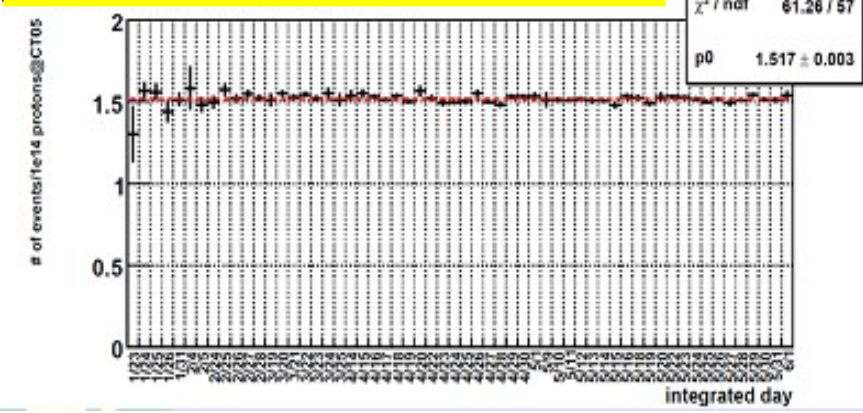
Typical event is one module



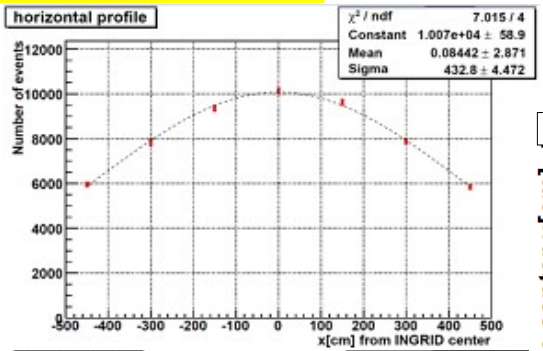
Event time

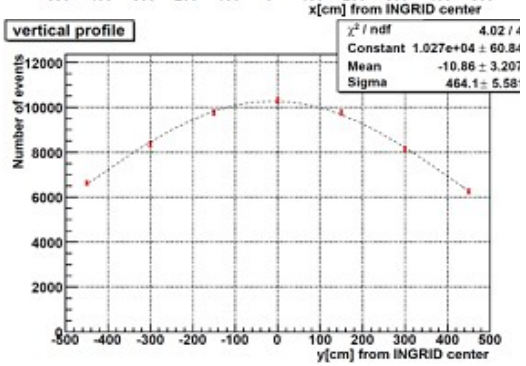


Event rate (per 1x10^{14} PoT)

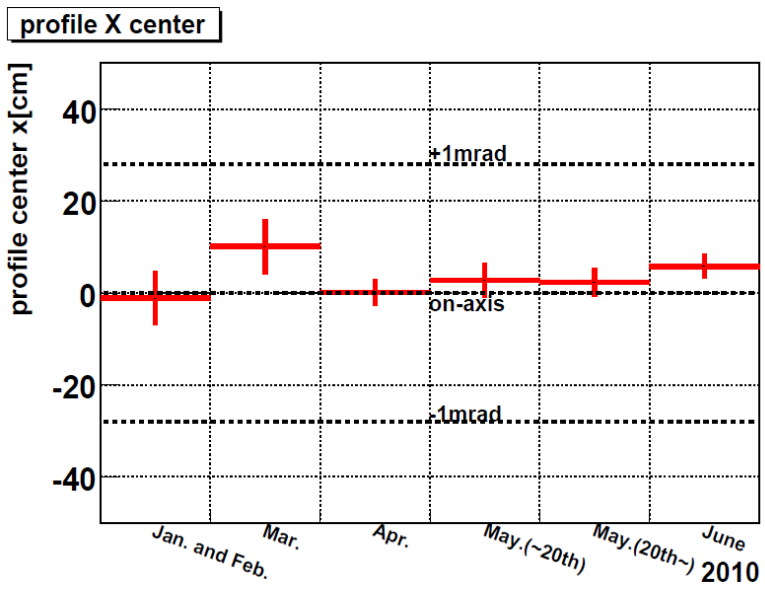


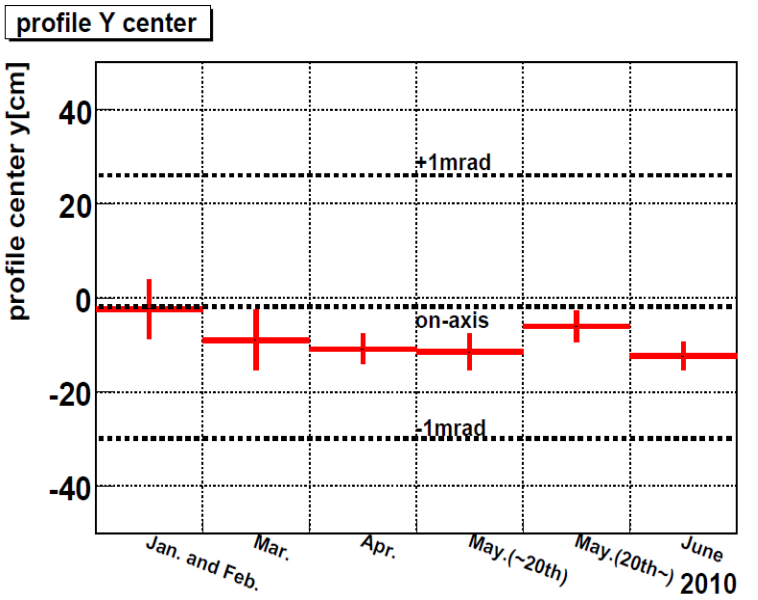
Beam profile



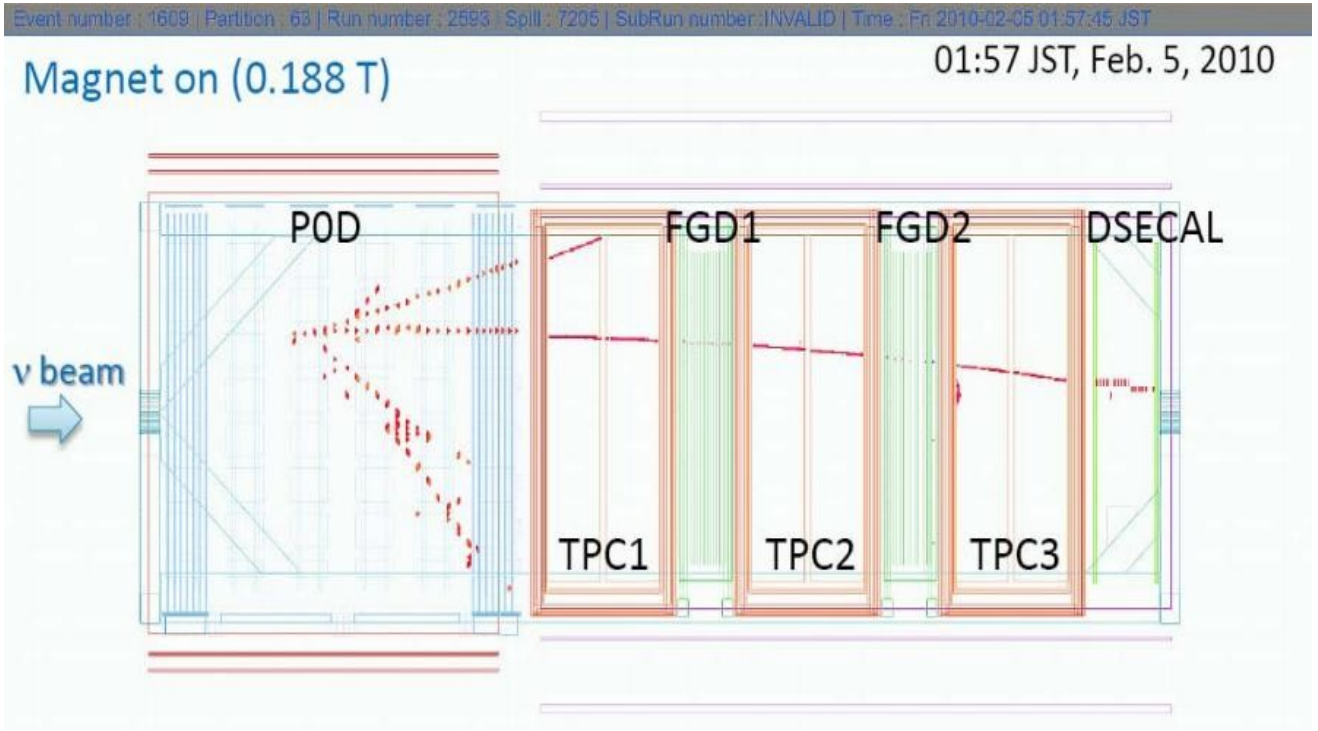


Profile center (from Gaussian fit) over run period



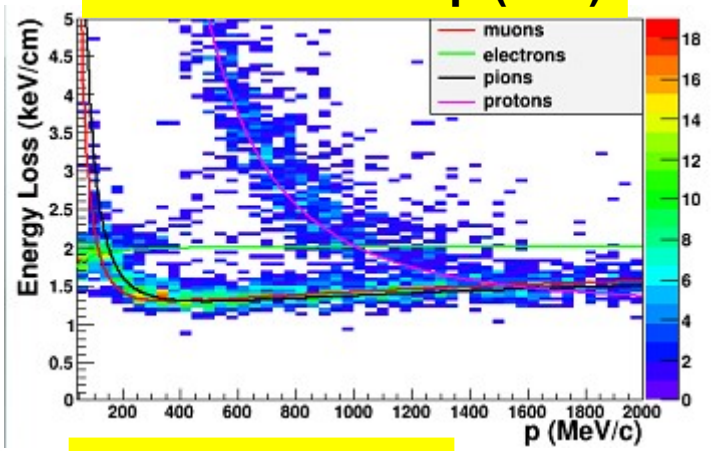


ND280

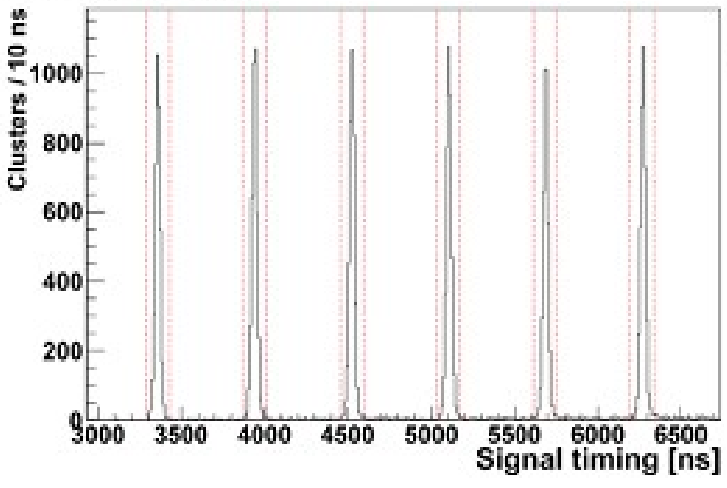


System	Channels	Bad chan.	Fraction
DSECAL	3400	11	0.3%
SMRD	4016	3	0.07%
P0D	10400	7	0.07%
INGRID	8360	8	0.1%
TPC	124416	12	0.01%
FGD	8448	32	0.4%

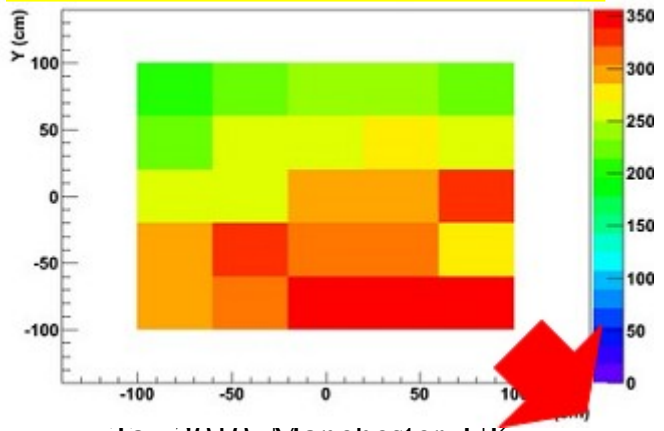
TPC: dE/dx vs p (+ve)



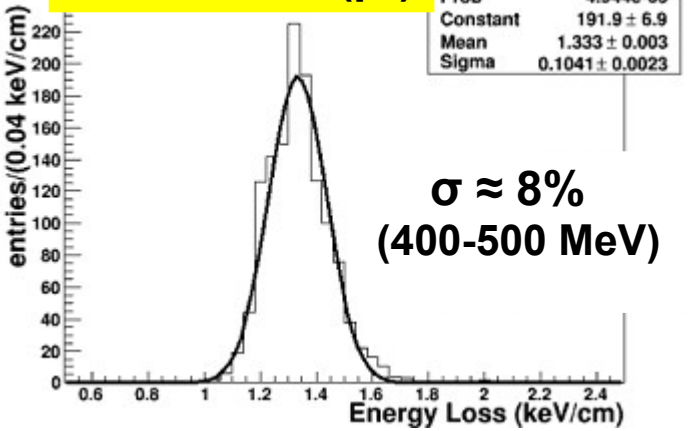
FGD cluster timing



P0D vertex position (x-y)



TPC: dE/dx (μ⁻)



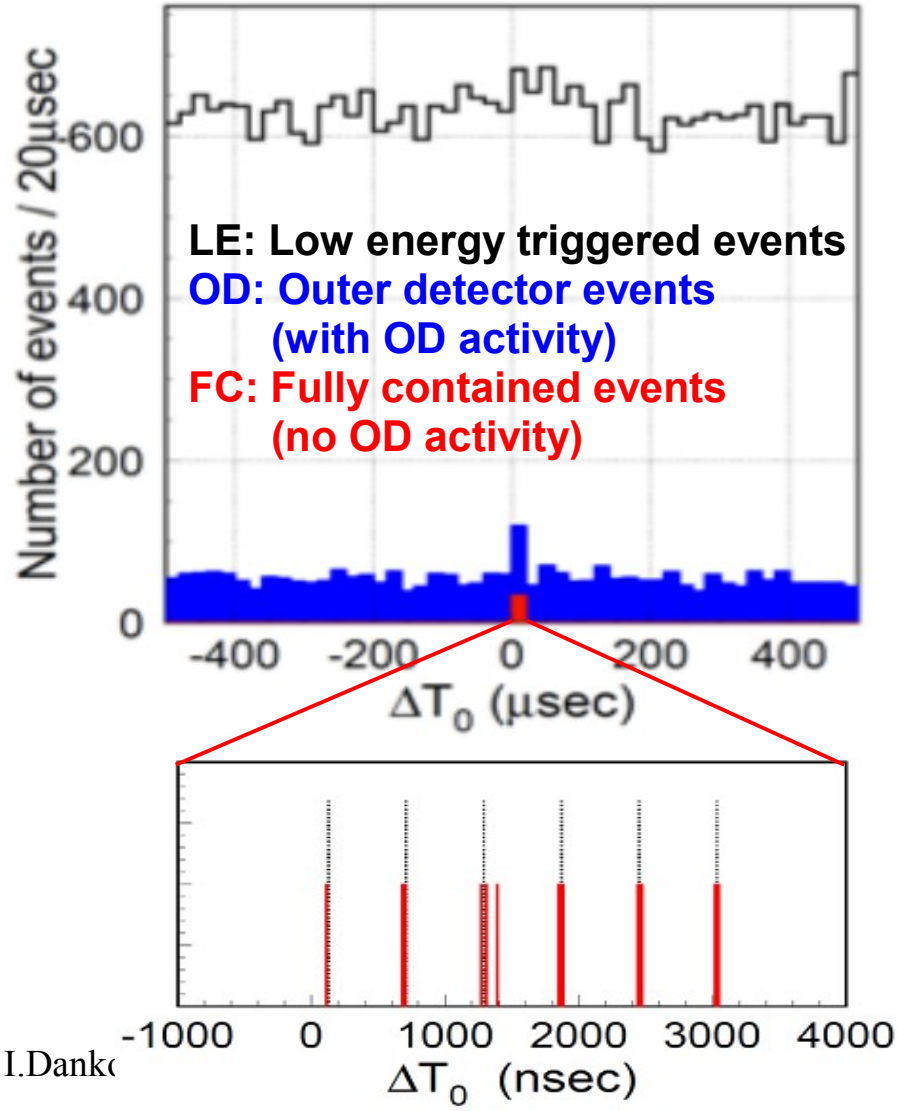
σ ≈ 8%
(400-500 MeV)

Super Kamiokande

Fully contained (FC) candidates: 33

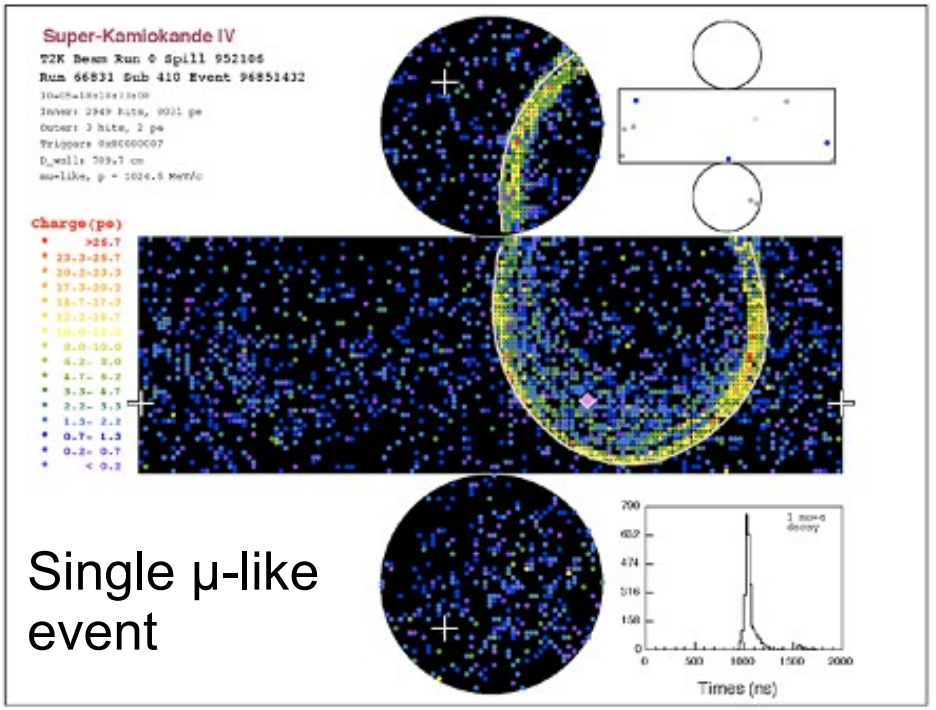
Fiducial volume & Evis>30 MeV: 23

Expected background < 10^{-2} events



Unbiased even selection

For ν_μ disappearance analysis	For ν_e appearance search
Timing coincidence w/ beam timing (+TOF)	
Fully contained (No OD activity)	
Vertex in fiducial volume (>2m from wall)	
Evis > 30MeV	Evis > 100MeV
Number of rings = 1	
μ-like ring	e-like ring
	No decay electron
	Forced 2nd ring: $m_{\gamma\gamma}$<105 MeV
	E_ν^{rec} < 1250MeV



Single μ-like event

Short and long term plans

2010 Summer/Fall shutdown

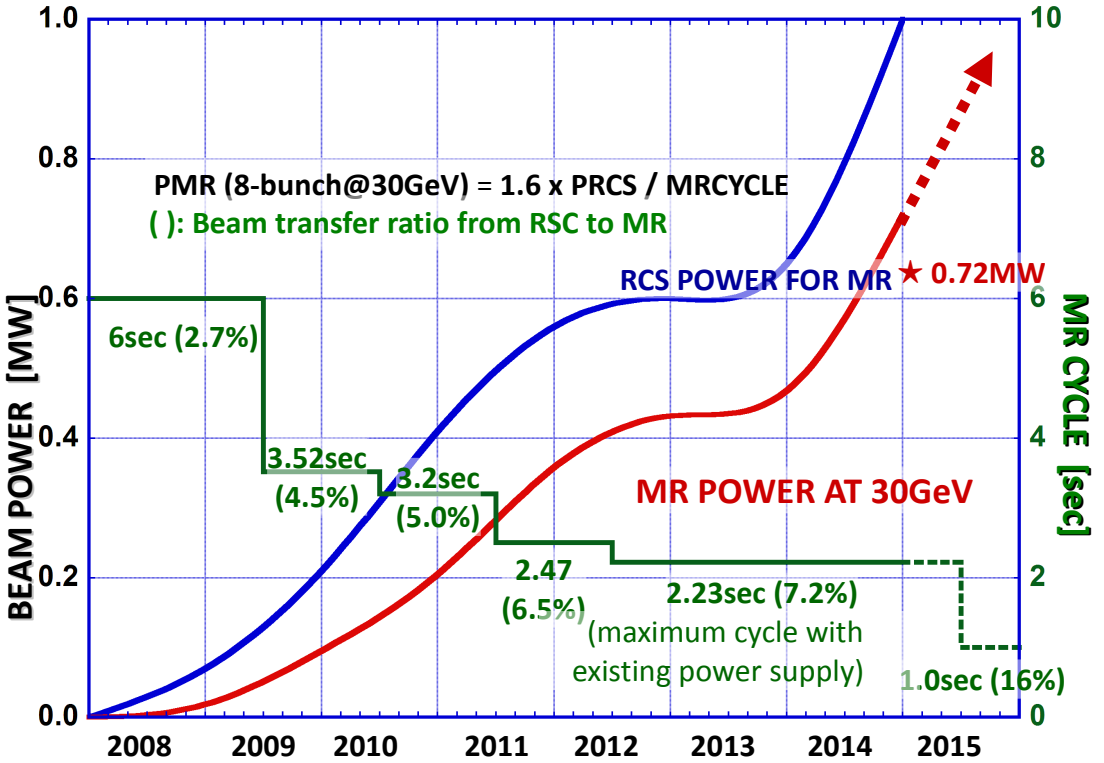
- New kicker magnets and power supplies: 6 → 8 bunch
- New horn power supplies: 250 kA → 320kA
- Barrel ECal installation will be completed by October
- 2 INGRID diagonal modules

Resume data taking in November

- aim 150 kW x 10^7s integrated power by July 2010

Long term plans:

- reduce MR cycle: 3.5 to 2.23 s
- increase LINAC energy: 181 to 400 MeV

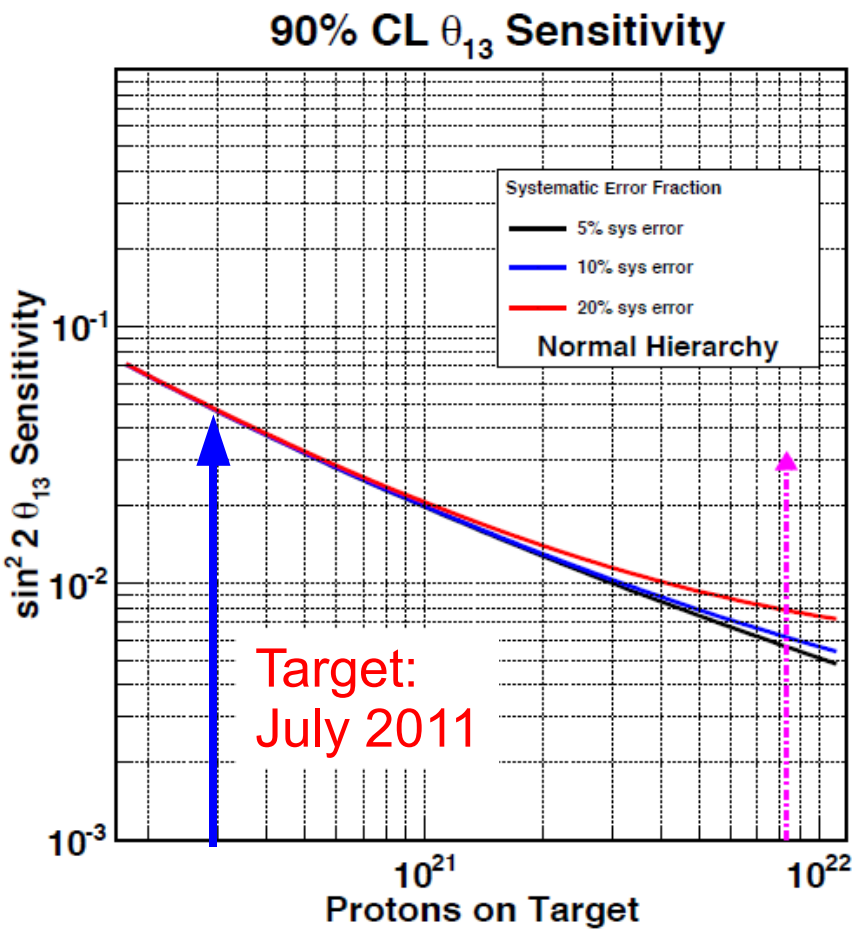


Sensitivity

- ν_e appearance:

$\sin^2 2\theta_{13} < 0.008$ (90% C.L.)

5 x 0.75 MW x 10^7s (8.3 x 10^{21} PoT)

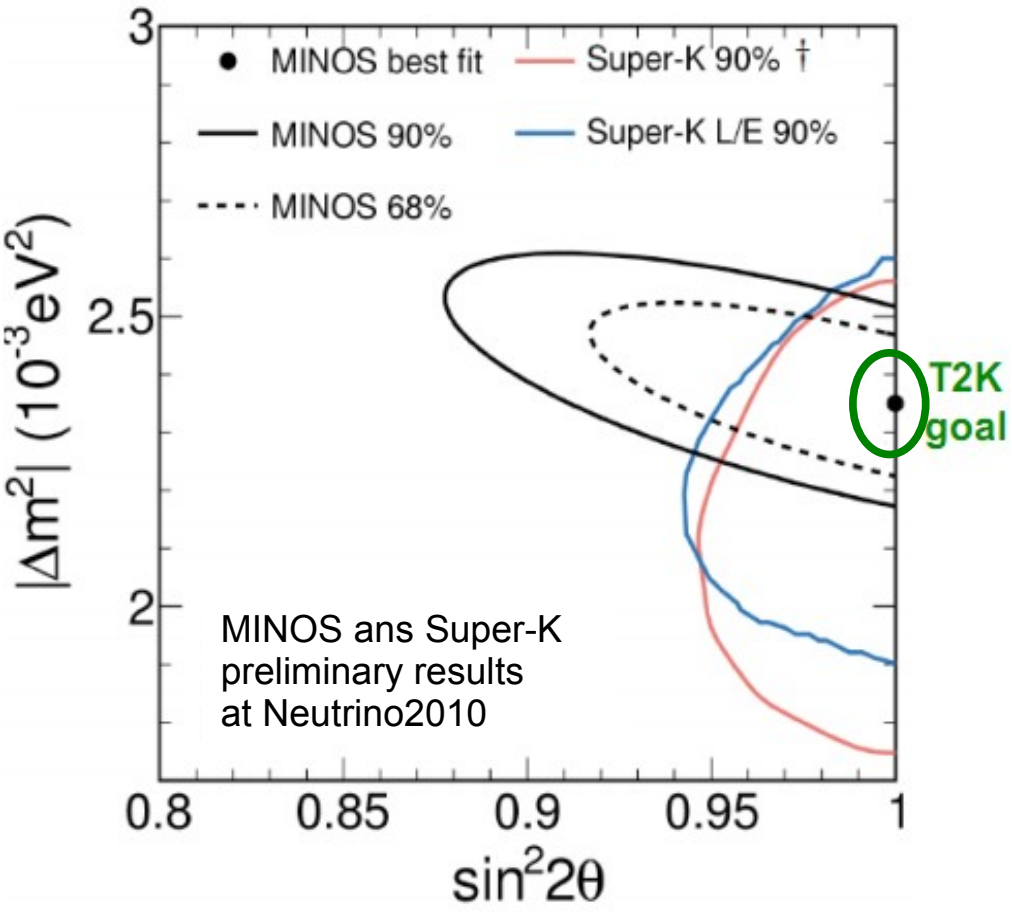


(Δm^2_{23}=2.4x10^{-3} eV^2, δ_{CP}= 0)

- ν_μ disappearance:

$\delta(\sin^2 2\theta_{23}) \approx 0.01$ & $\delta(\Delta m^2_{23}) < 1\text{x}10^{-4}$ eV^2 (90% C.L.)

5 x 0.75 MW x 10^7s (8.3 x 10^{21} PoT)



Summary

- T2K: first high intensity, off-axis long-baseline neutrino oscillation experiment
- New accelerator complex, beam line, and near detectors were finished last year
- First physics data taking concluded earlier this year – data analysis is under way
- Continuous running resumes after the Summer shutdown in November
- Stay tuned: first physics results are expected soon

Extra slides

T2K collaboration

~500 members, 61 Institutes, 12 countries

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. Padova
INFN, U. Bari

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
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroclaw

Russia
INR

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

Spain
IFIC, Valencia
U. A. Barcelona

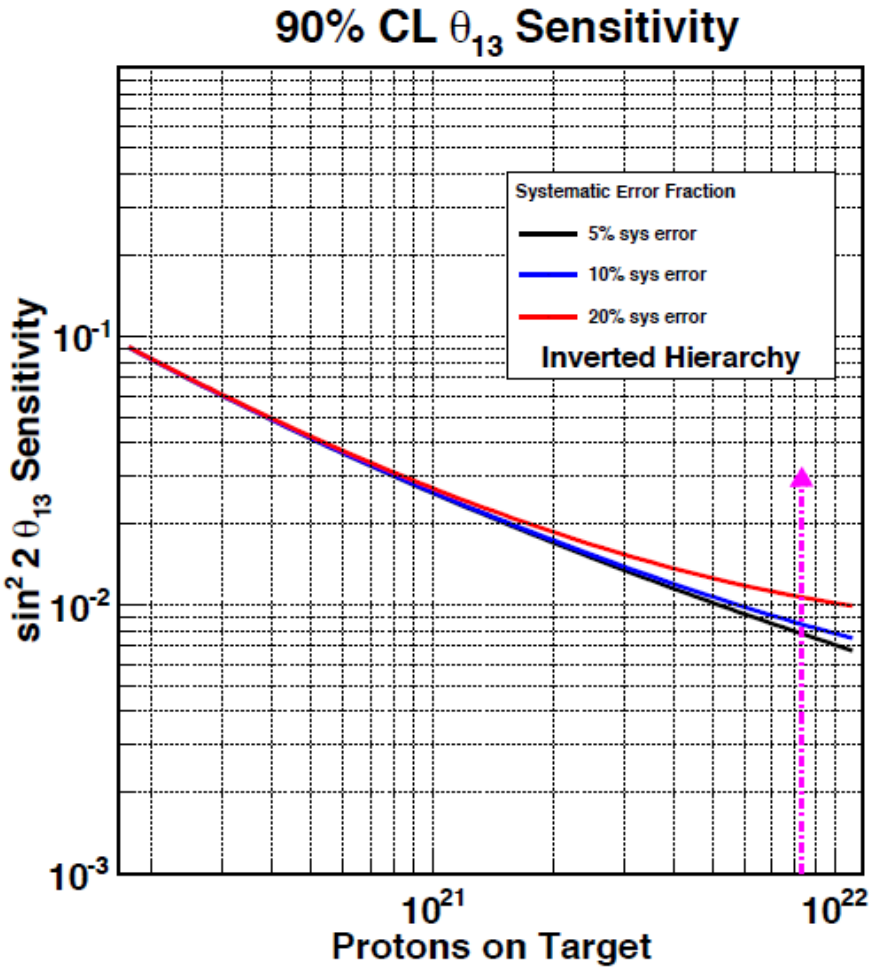
Switzerland
U. Bern
U. Geneva
ETH Zurich

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

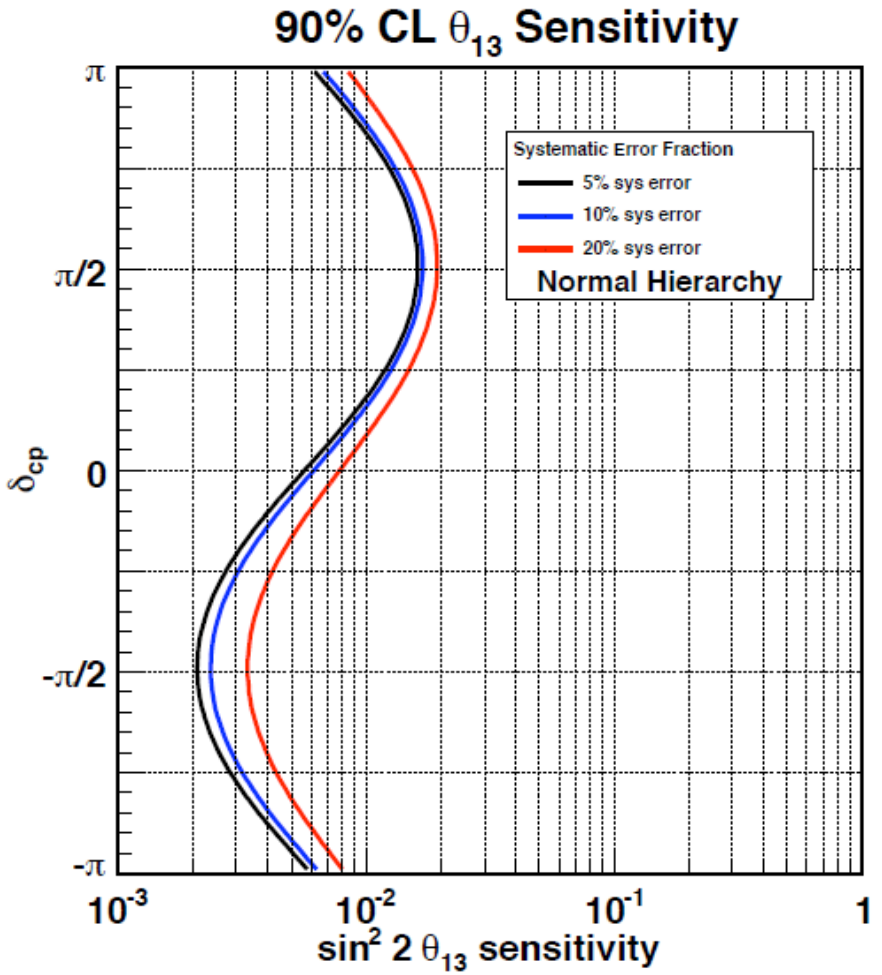
USA
Boston U.
B.N.L.
Colorado S. U.
Duke U.
Louisiana S. U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

Sensitivity for θ_{13}

Inverted hierarchy



as a fn of δ_{CP} (normal hierarchy)



δ_{CP} can enhance or reduce the signal