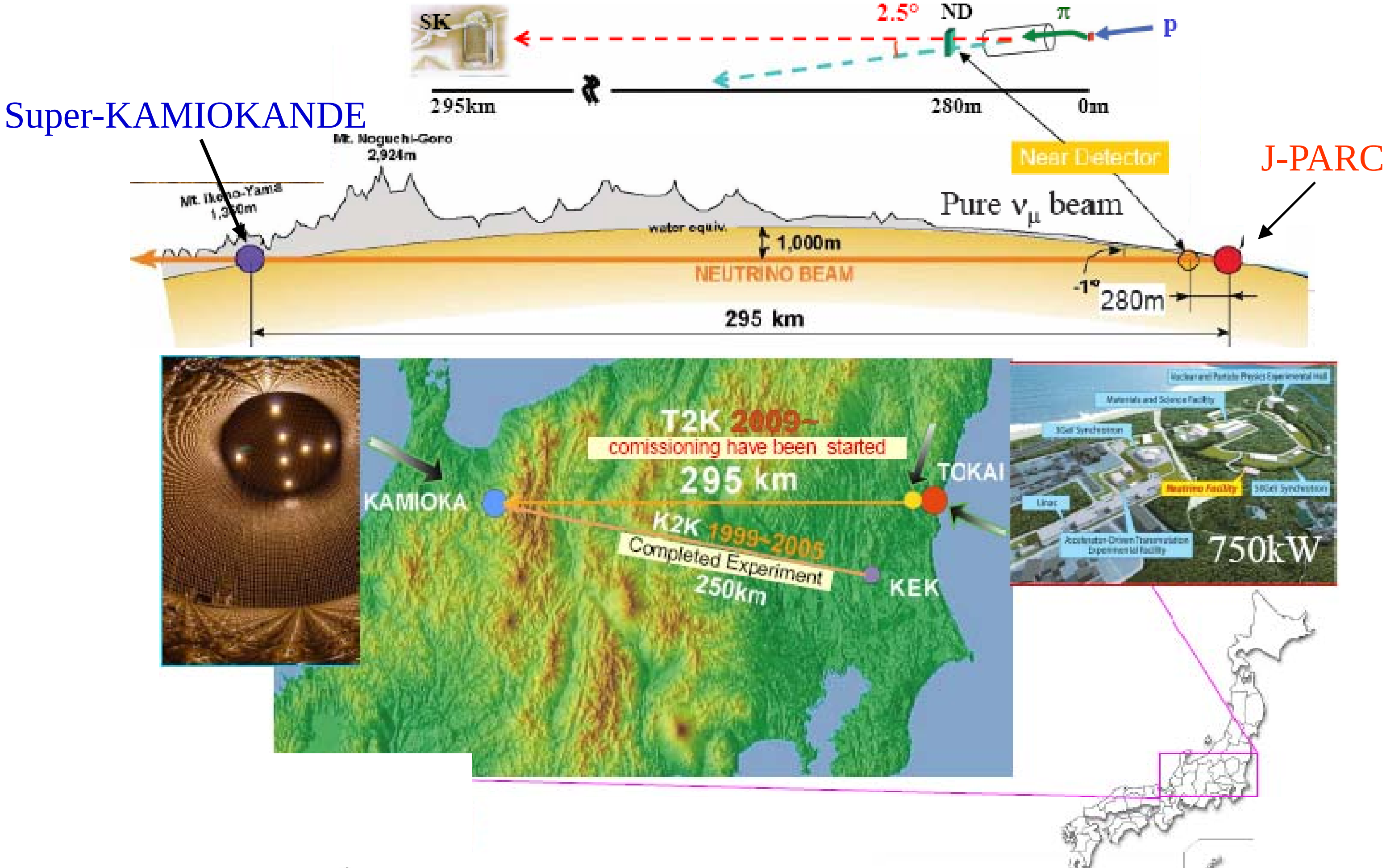
Status of the T2K experiment
(Tokai to Kamioka)

Alessandro Bravar
for the T2K collaboration

The T2K experiment

next generation long-baseline (295 km) neutrino oscillation experiment
intense ν_μ beam generated by new J-PARC facility (~MW facility)
off axis beam (2.5^0) almost monochromatic, ν energy tuned to oscillation maximum
$\rightarrow$ suppression of neutral current π^0 background events from higher energy tail
near and far detectors



ν oscillations

neutrino flavor eigenstates (e, μ, τ) are different from mass eigenstates (1,2,3)
$\Rightarrow$ neutrino mixing: probability of observing a given ν flavor will vary with time
$\Rightarrow$ neutrinos have mass

the MNSP mixing matrix relates the mass states to the flavor states

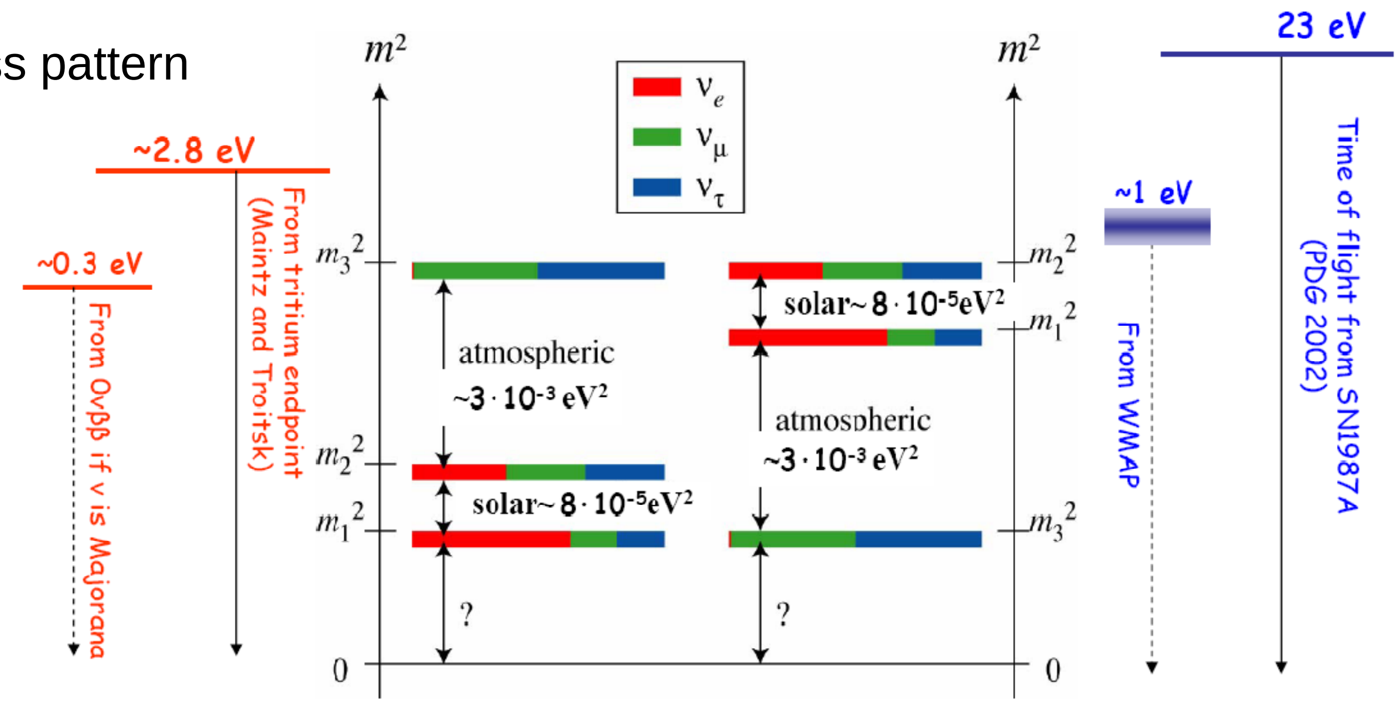
$$\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \cdot \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13} e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -\sin\theta_{13} e^{-i\delta_{CP}} & 0 & \cos\theta_{13} \end{pmatrix} \cdot \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{-i\alpha/2} & 0 \\ 0 & 0 & e^{-i\beta/2} \end{pmatrix}$$

$\theta_{23} \sim 45^0$	$\theta_{13} < 7^0$ @ 90%CL	$\theta_{12} \sim 32^0$	
SuperK (atm. ν)	Chooz	solar ν	neutrinoless
K2K	future reactors	KamLAND	double beta
Minos	T2K	future solar ν exp.	decay
T2K			

Issues in ν physics

absolute mass scale
neutrino mixing θ_{13} = ? $\rightarrow$ CP violation ? addressed by T2K
choice of hierarchy
Dirac or Majorana ?

ν mass pattern



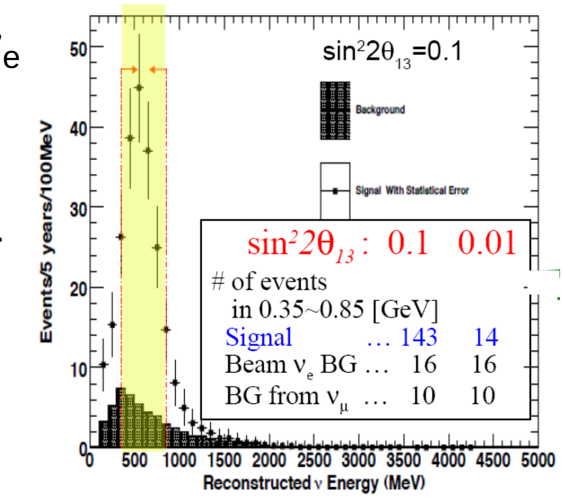
normal
hierarchy

inverted
hierarchy

T2K physics goals

measure θ_{13}, $|\Delta m^2_{13}|$ by searching for ν_e appearance: $\nu_\mu \to \nu_e$

- $\sin^2(2\theta_{13}) < 0.008$ (@ 90% CL) (depends also on δ_{CP})
- is $\theta_{13} \neq 0$?
- $\rightarrow$ fisrt step toward CP violation searches in lepton sector



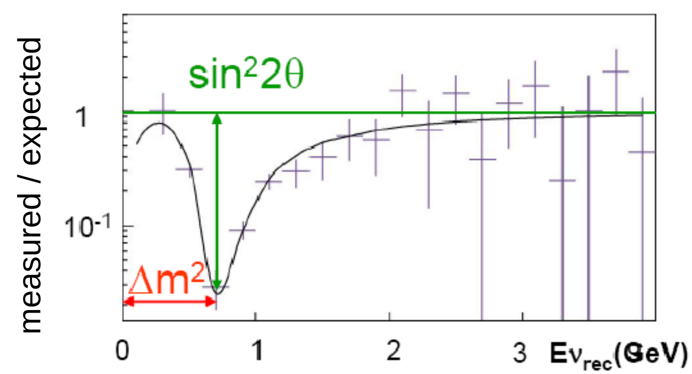
$$P_{\mu\to e} \approx \sin^2 2\theta_{13} \sin^2 \theta_{23} \sin^2\left(1.27\ \Delta m^2_{13}\ L/E_\nu\right)$$

common for normal hierarchy

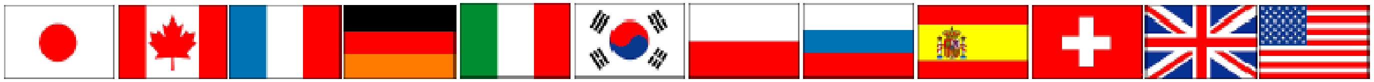
better measurement of θ_{23}, Δm^2_{23} by studying ν_μ disappearance: $\nu_\mu \to \nu_x$

- $\delta(\sin^2(2\theta_{23})) \sim 0.01$ $\delta(\Delta m^2_{23}) < 1\times10^{-4}$ ev^2 (@ 90% CL)
- is θ_{23} maximal ?

$$P_{\mu\to x} \approx 1 - \sin^2 2\theta_{23} \sin^2\left(1.27\ \Delta m^2_{23}\ L/E_\nu\right)$$



The T2K collaboration



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U.of British Columbia
U. of Regina
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U. of Victoria
York U.

France
CEA Saclay
IPN Lyon
LLR E. Poly
LPNHE-Paris

Germany
RWTH Aachen U.

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INFN Bari
INFN Roma
Napoli U.
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Rome U.

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

Korea
Chonnam Nat'l U.
Dongshin U.
Sejong U.
Seoul Nat'l U.
Sungkyunkwan U.

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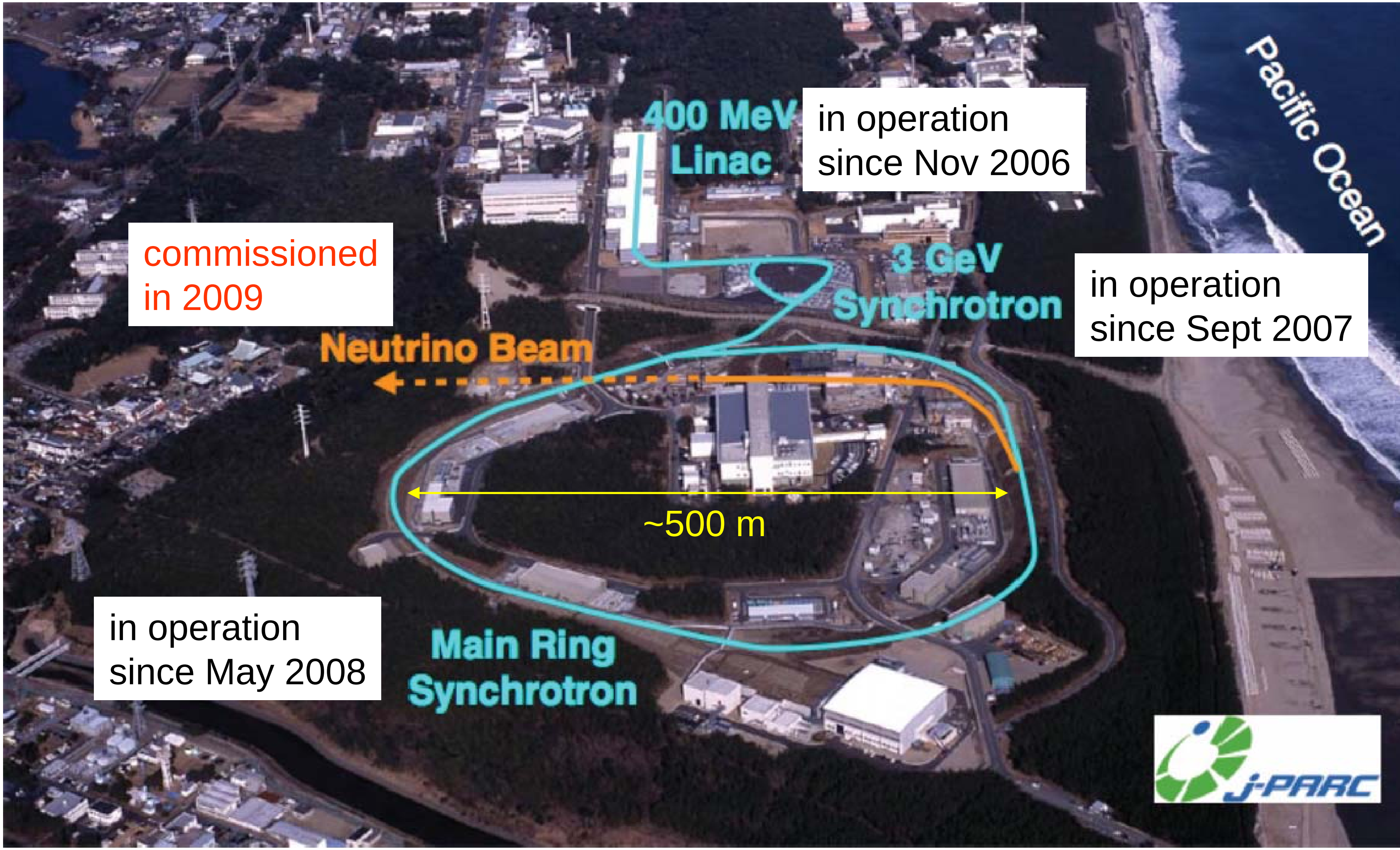
U. of Colorado
U. of Pittsburgh
U. of Rochester
U. of Washington

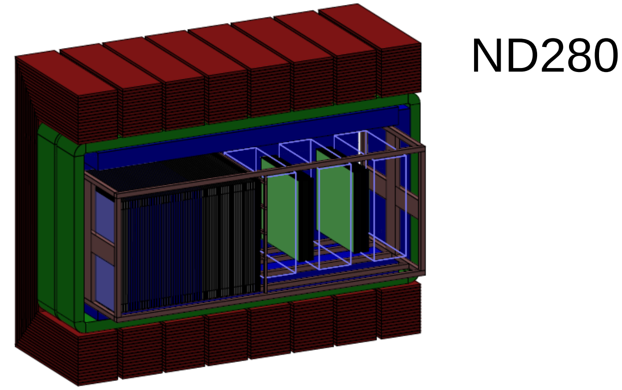
almost 500 members from 62 institutes in 12 countries

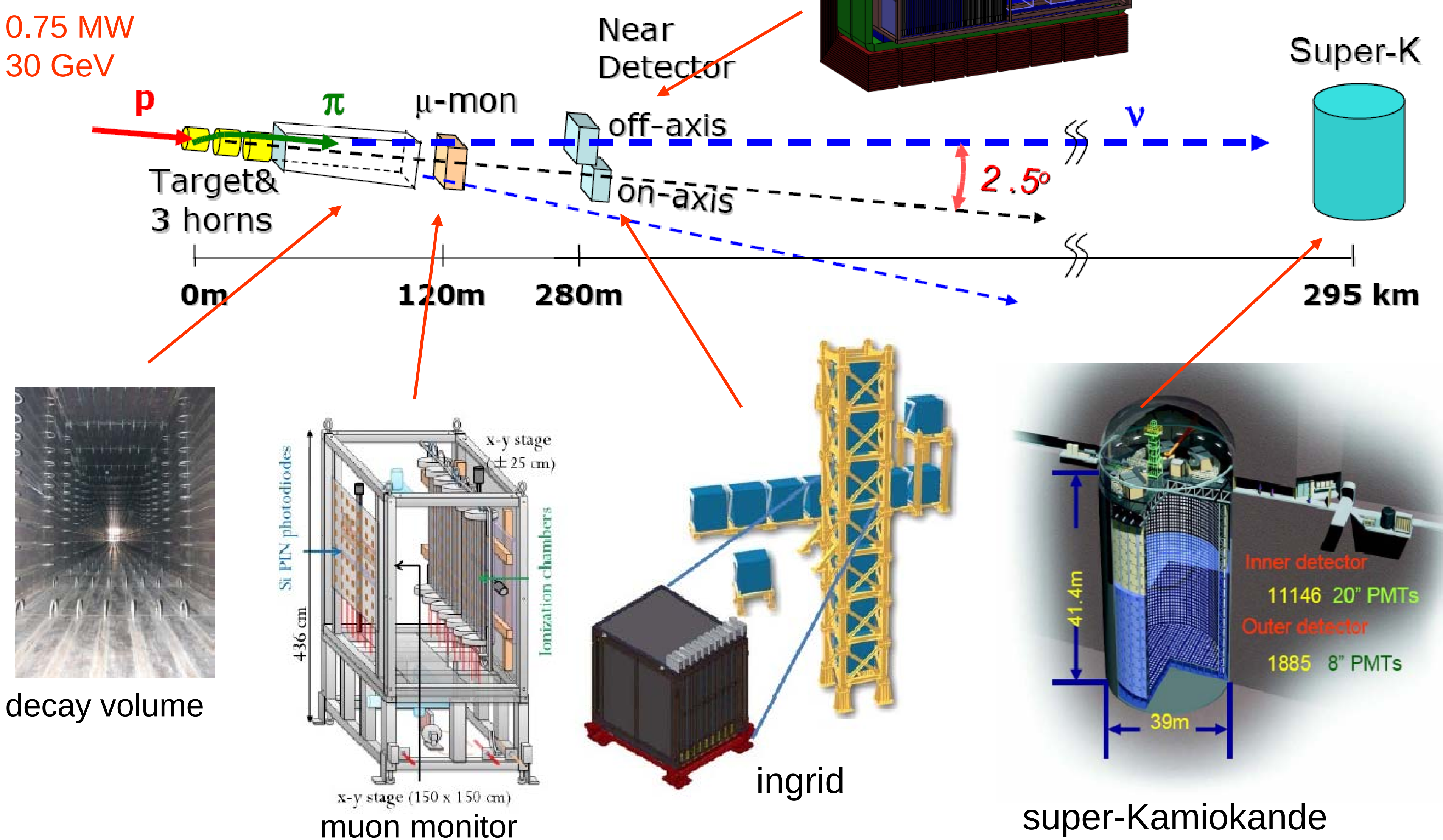
J-PARC accelerator complex



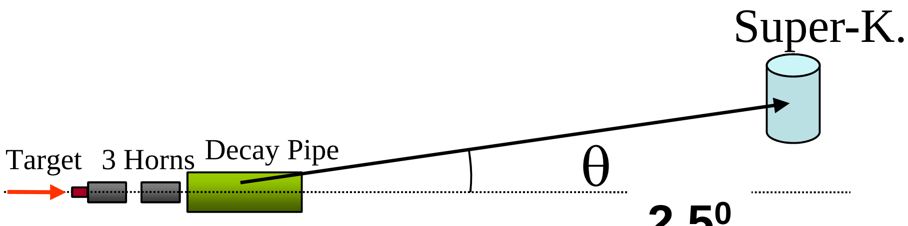
all parts of the accelerator chain are now operational including the neutrino beam-line

T2K setup


ND280

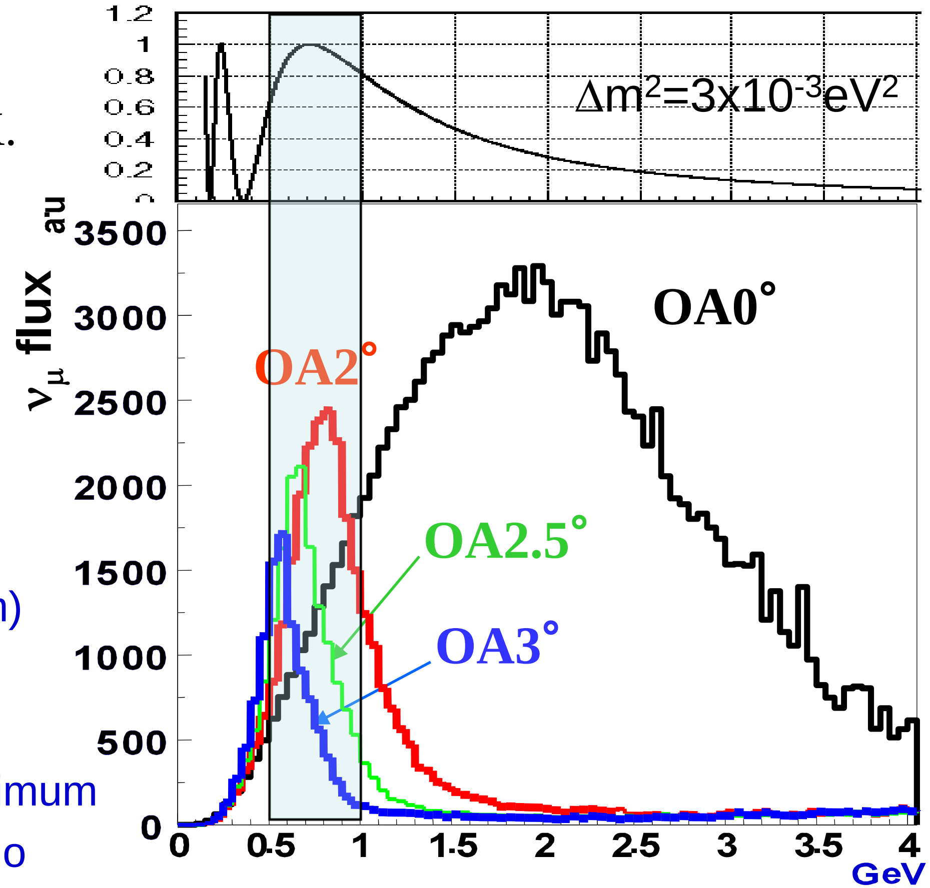

0.75 MW
30 GeV
p
π
μ-mon
Near
Detector
off-axis
ν
Super-K
Target&
3 horns
on-axis
2.5°
0m
120m
280m
295 km
x-y stage
(± 25 cm)
Si PIN photodiodes
Ionization chambers
436 cm
x-y stage (150 x 150 cm)
Inner detector
11146 20" PMTs
Outer detector
1885 8" PMTs
41.4m
39m
decay volume
muon monitor
ingrid
super-Kamiokande

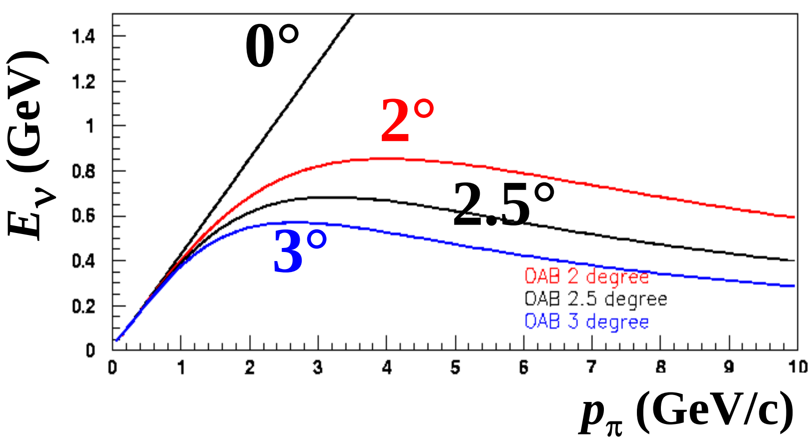
The off-axis ν beam



π decay Kinematics

- ND280 and Super-K are at the same 2.5^0 off ν beam axis angle
- Very narrow energy spectrum with small high energy tail (almost monochromatic beam)
- Neutrino flux at interesting energy region higher than for on-axis setting
- Neutrino beam energy “tuned” to oscillation maximum
- Reduces the backgrounds in the electron neutrino measurements (NC π^0 background)





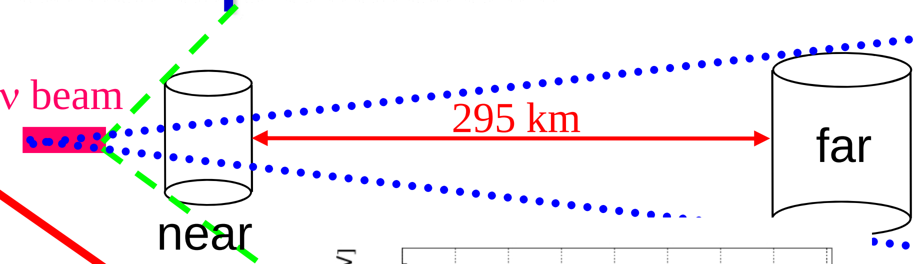
- neutrino energy E_ν almost independent of parent pion energy
- horn focusing cancels partially the p_T dependence of the parent pion

in reality things are more complicated and the predicted ν spectrum depends on the hadro-production models used

Far / Near flux ratio extrapolation

ν spectrum at far site is different from near site even w/o oscillations

effect of non-point-like source



Expected flux at SK

$$\Phi_{SK}^{\exp} = R_{F/N} \cdot \Phi_{ND}^{obs}$$

Far / Near ratio

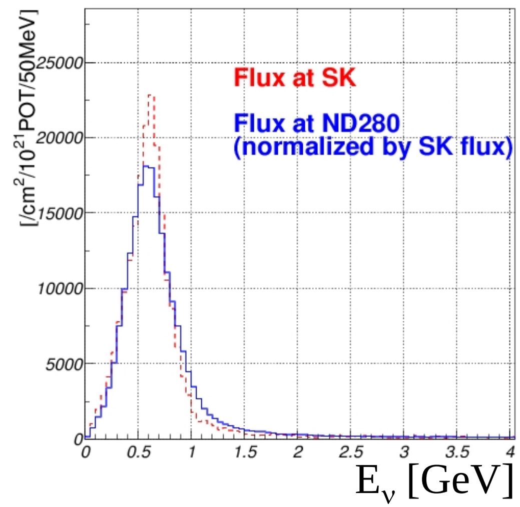
$$R_{F/N} = \Phi_{SK} / \Phi_{ND}$$

σ, ε

SK expected obs.

SK observation

determined by hadro–production and geometry

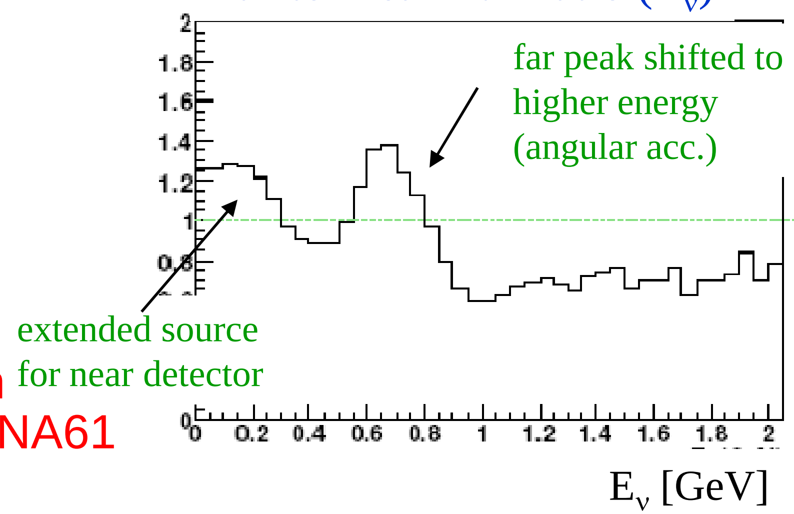


Near and far detectors see different solid angles:

- far detector: point-like source at 2.5^0
- near detector: extended source 1^0 to 3^0

$\Rightarrow$ complicated far to near flux ratio

Far-to-Near flux ratio (E_ν)

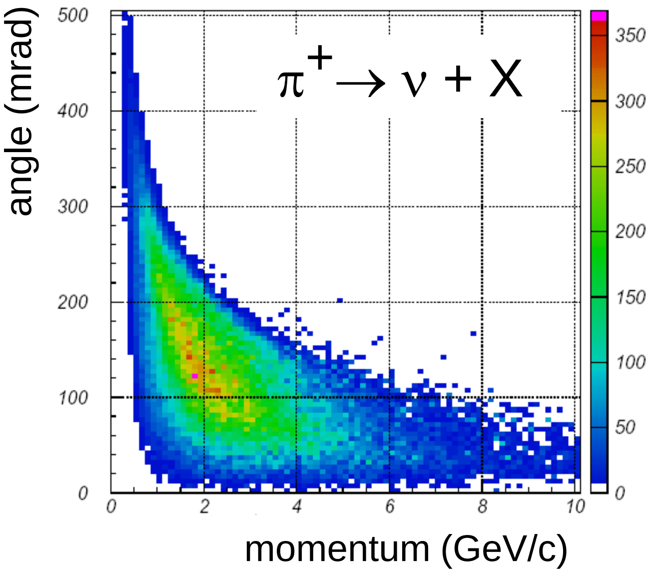


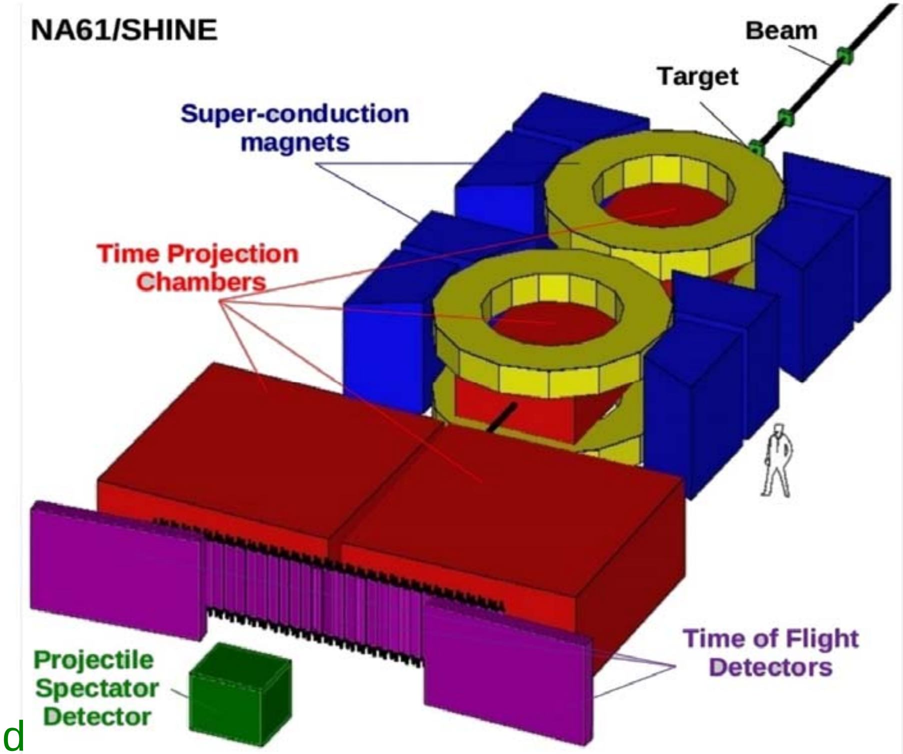
to predict the ν flux ratio correctly need to know the details of the ν parent hadro-production kinematics

no measurement of particle production off carbon with 30 GeV protons over same phase space ➔ NA61

The NA61 hadro-production exp.t @ CERN

ν parent hadron phase space





In order to cover this kinematical region and identify the outgoing hadrons requires a detector with large acceptance and particle ID

To achieve the T2K physics goals measure π and K hadro-production to

predict Far / Near ν flux ratio to 3%
predict the neutrino flux to 5%

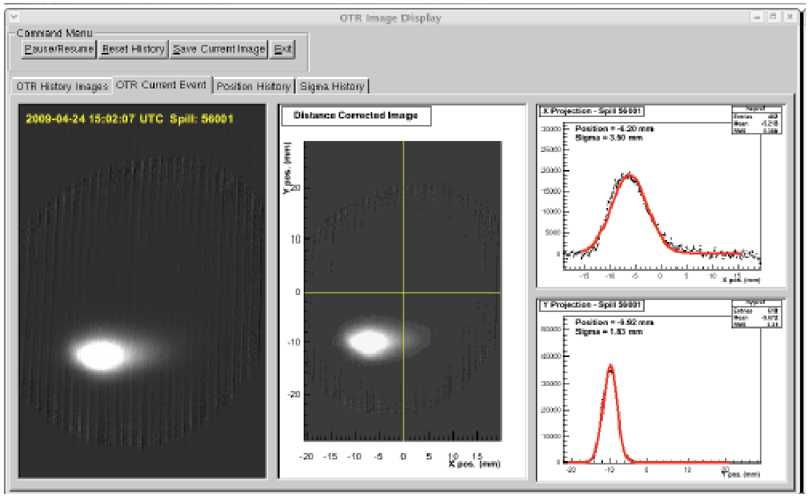
T2K replica target used in NA61

Preliminary hadro-production results available

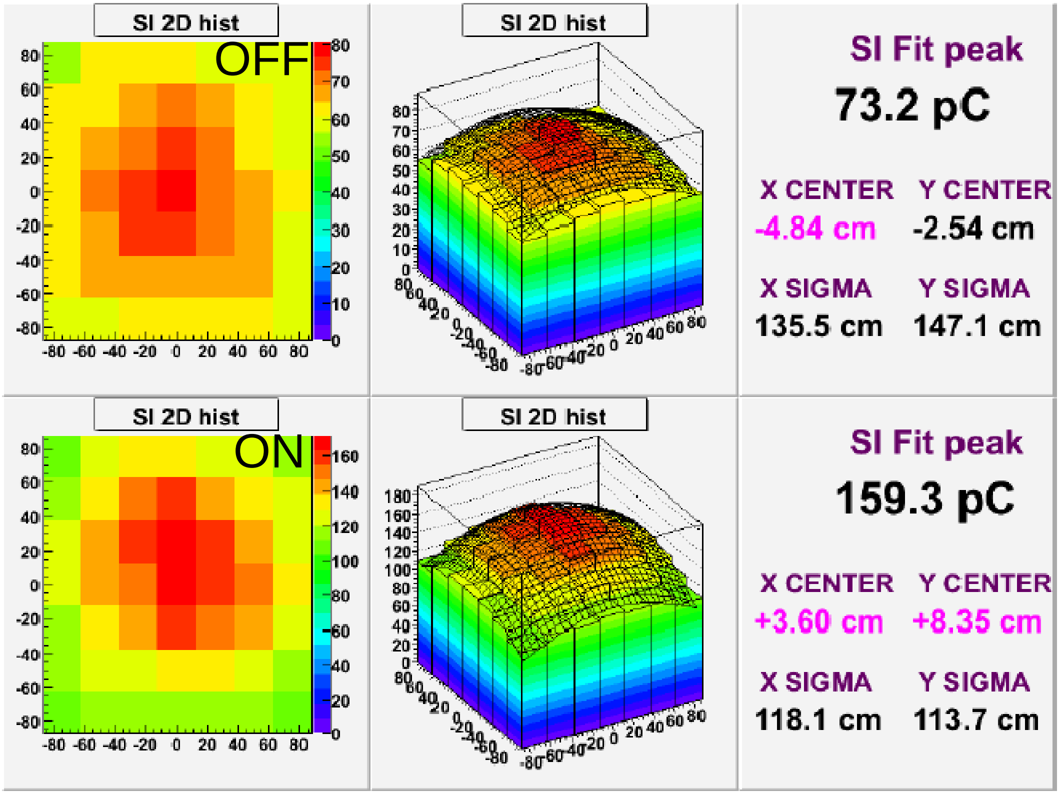
First beam on T2K target

First protons on target April 24th, 2009

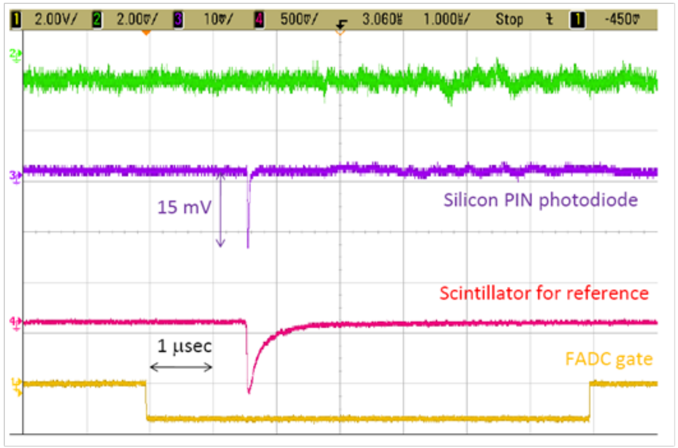
Fluorescent image in proton beam position monitor 30 cm upstream of target



effect of horn focusing (horn-1) in muon monitor Si-PIN photodiode array just behind the beam dump



Muon monitor signal



Beam commissioning progress

April - May 2009

- first beam commissioning
- primary beamline components installed
- 1st horn installed
- muon monitor installed

Nov - Dec 2009

- all 3 horns installed
- all beam instrumentation installed
- operation in 6 bunch mode
- fine beam tuning
- achieved continuous operation with
  2×10^{12} p / bunch $\times$ 6 (~ 20 kW)
- high intensity trial with
  5×10^{12} p / bunch $\times$ 6 (~ 50 kW)

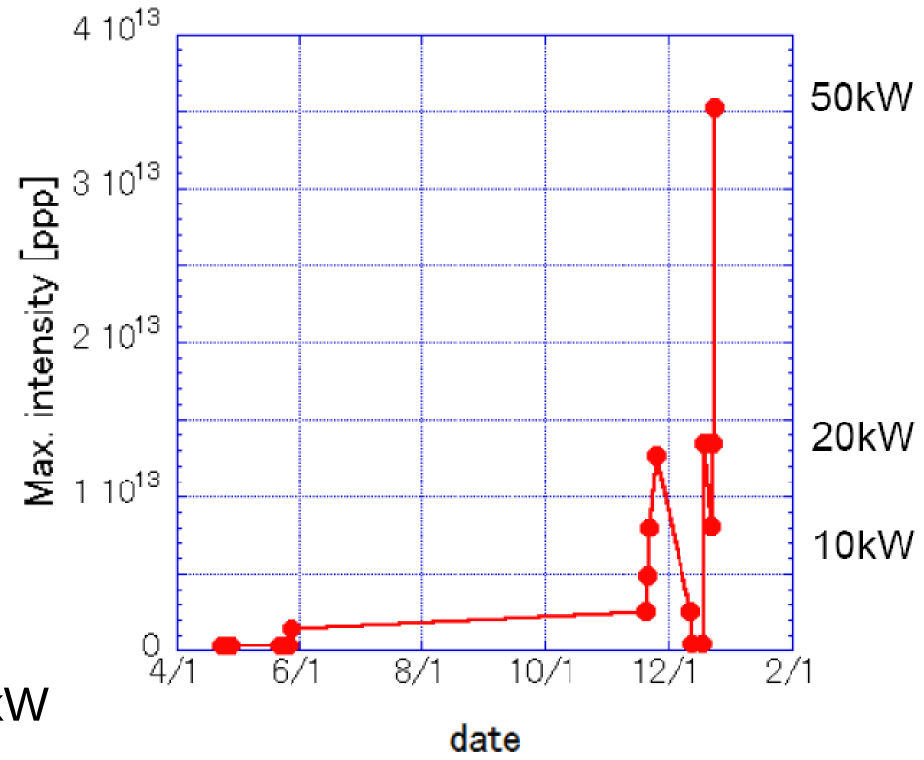
Jan - Feb 2010

- work on increasing beam power to 100 kW

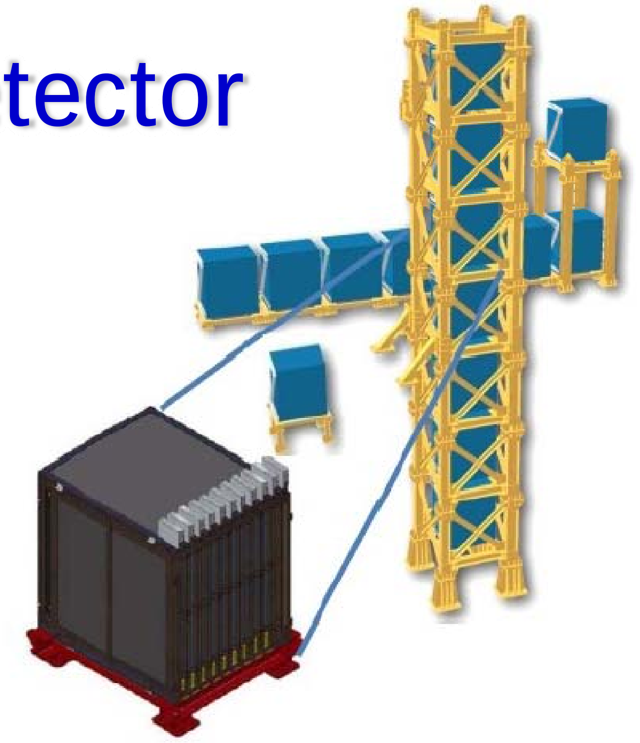
First physics run planned to start from March 2010

- aim to accumulate 100 kW $\times$ 10^7 sec on target

beam power on T2K target

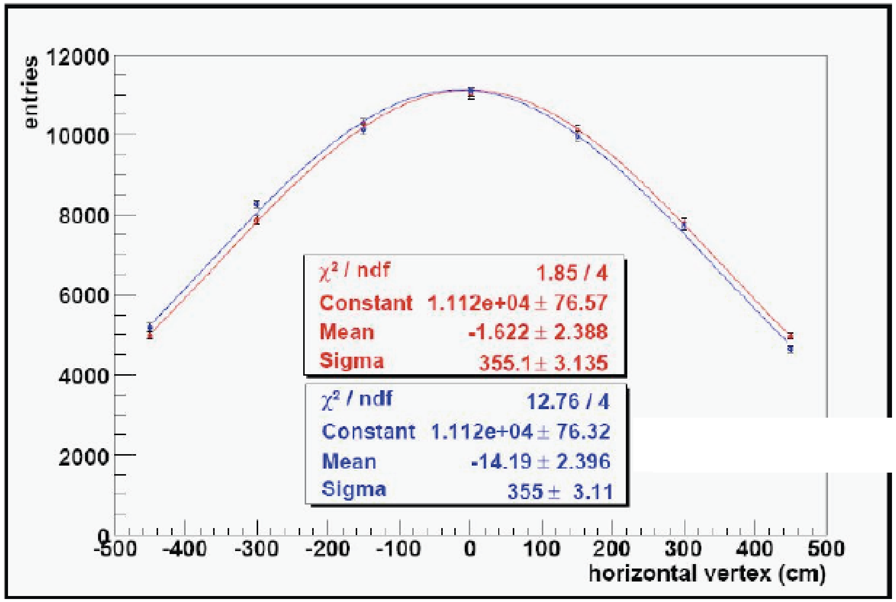


INGRID – On-Axis near detector



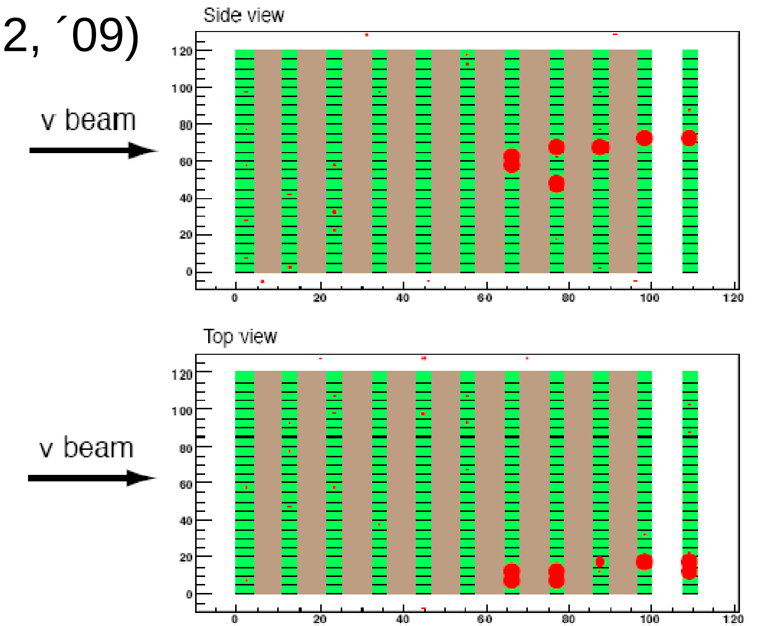
monitors ν beam direction

- 280 m from target
- 16 modules in the shape of a cross
- each module is an iron / scintillator calorimeter

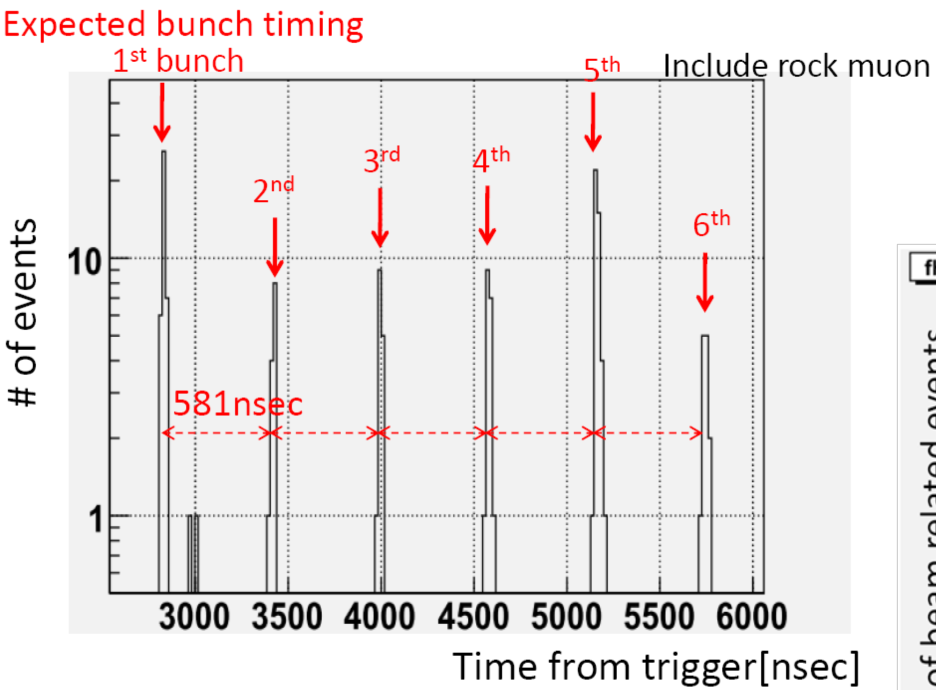


sensitive to primary proton beam targetting angle
can measure ν beam direction better than 1 mrad
→ feedback to beam tuning system

INGRID first ν event candidate
(Nov. 22, ´09)

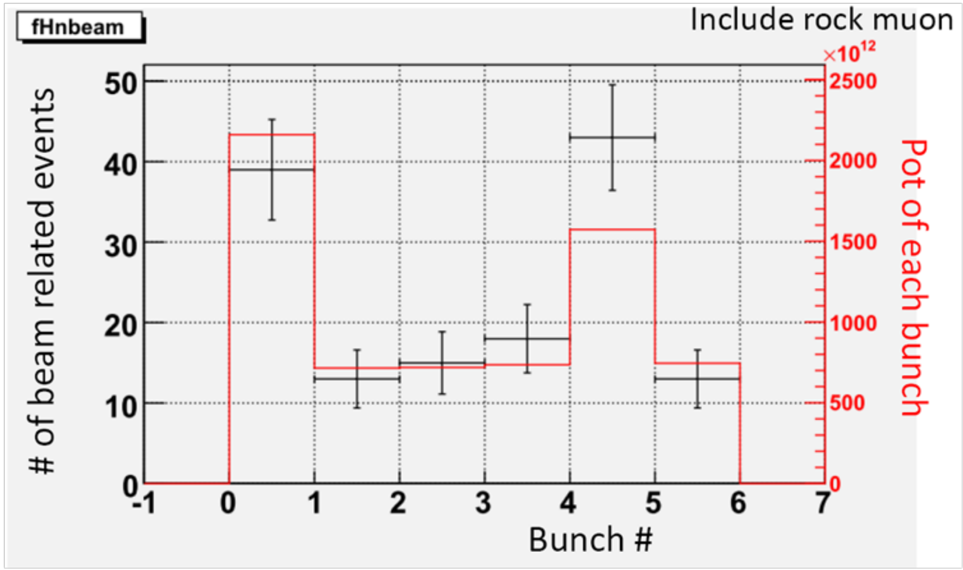


Beam events in INGRID



6 bunch operation:
each peak corresponds to a bunch

various bunch configurations used for commissioning purpose,
Including single bunch operation



correlation between # of events and bunch intensity (PoT)

ND280 Off-Axis detector overview

Measure neutrino beam spectrum prior to oscillations
and neutrino interaction ×-sections

All sub-detectors inside the
UA1 / NOMAD magnet (~0.2 T)

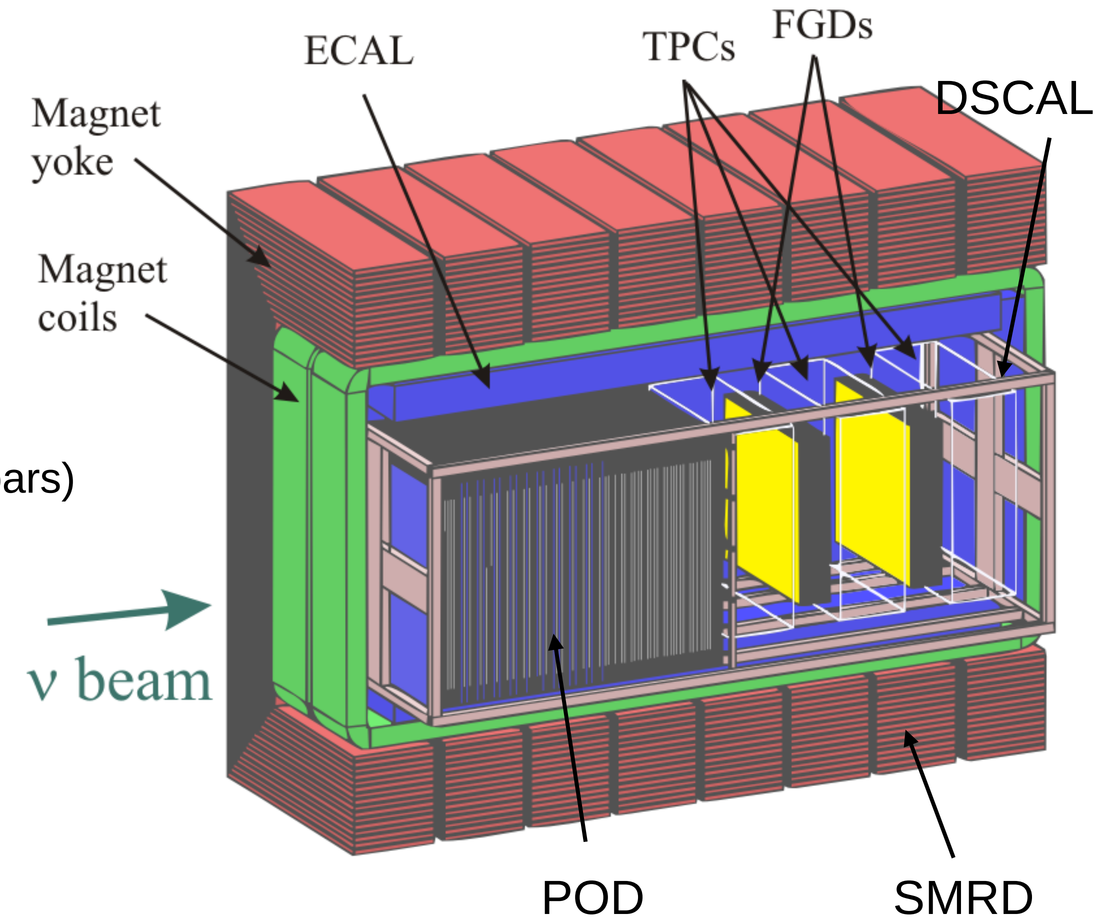
At full beam intensity
~ 10 k ν interactions / day

Tracker
- 3 TPCs with MicroMegas readout
- 2 fine grained detectors (scintillator bars)

POD – Pi-zero detector
- brass/scintillator tracking calorimeter designed to measure π^0 production in NC and CC on water target

ECAL
- lead scintillator sampling calorimeter

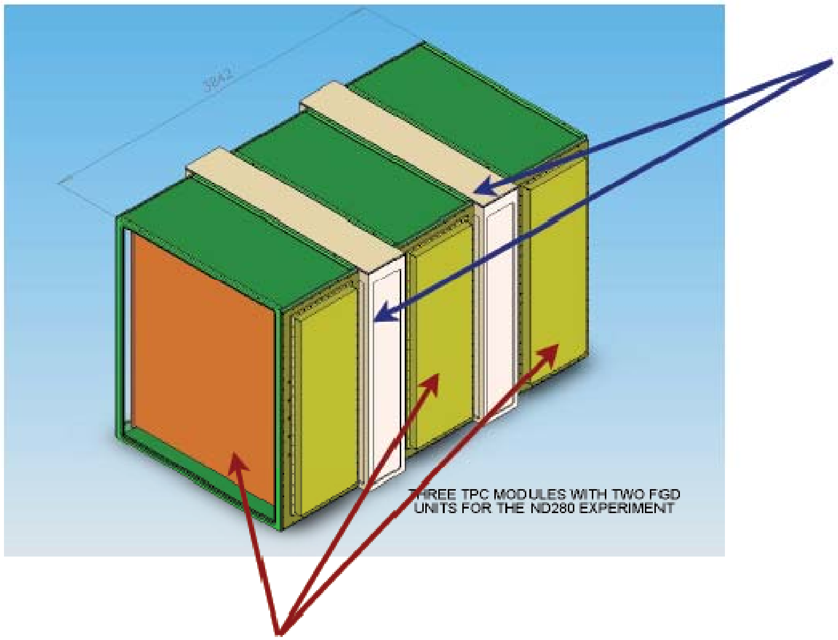
Side Muon Range Detector
- detects “lateral” muons

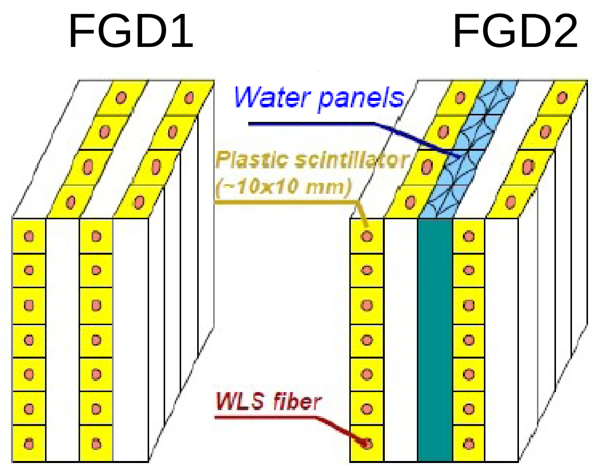


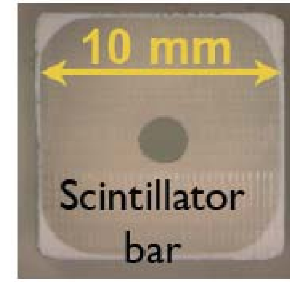
ND280 tracker

2 Fine Grained Detectors
1 cm^2 square scintillator bars
WLS fiber readout coupled to Si PM

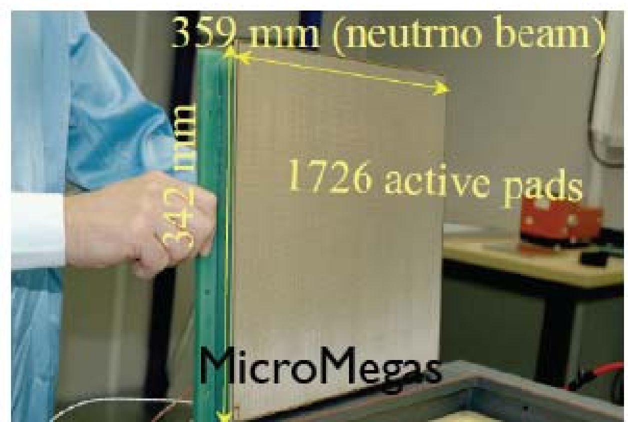
designed to study CC and NC final sates



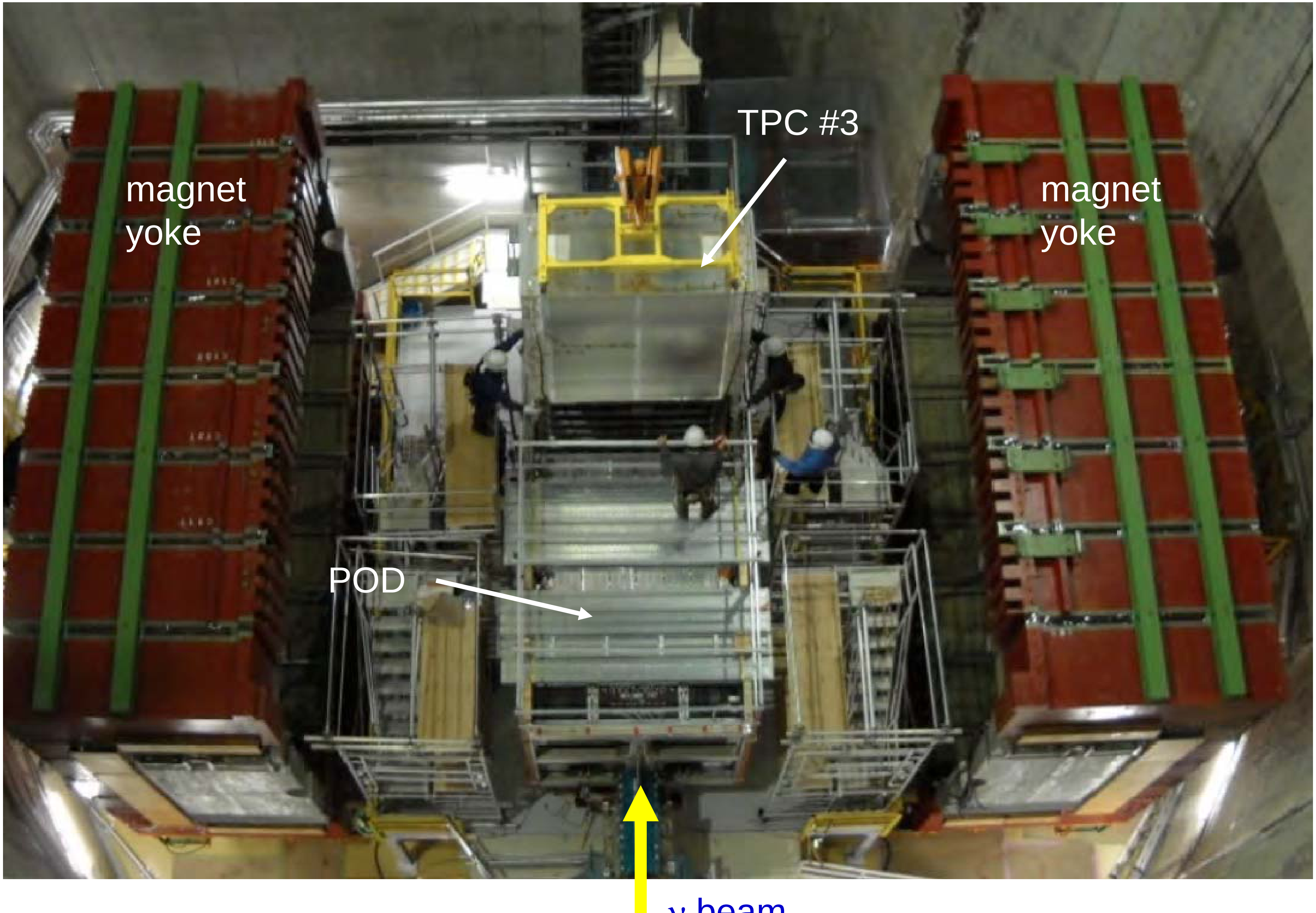




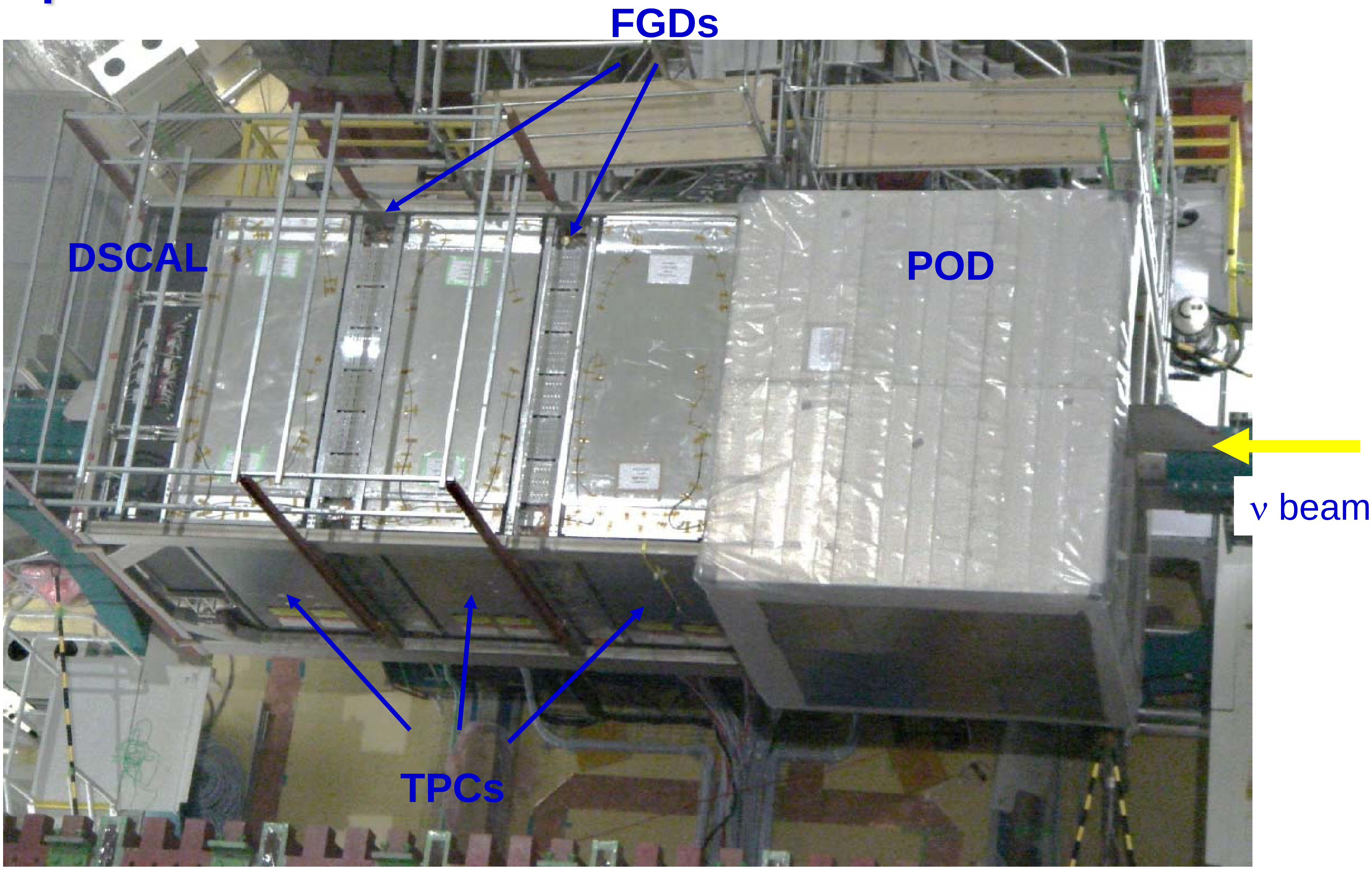
3 Time Projection Chambers
readout with MicroMegas
detectors (7 mm × 10 mm pads)
5σ e/μ separation (dE/dx measurement)
high resolution tracking (~ 0.2 T field)
σ_p / p < 10%



TPC installation

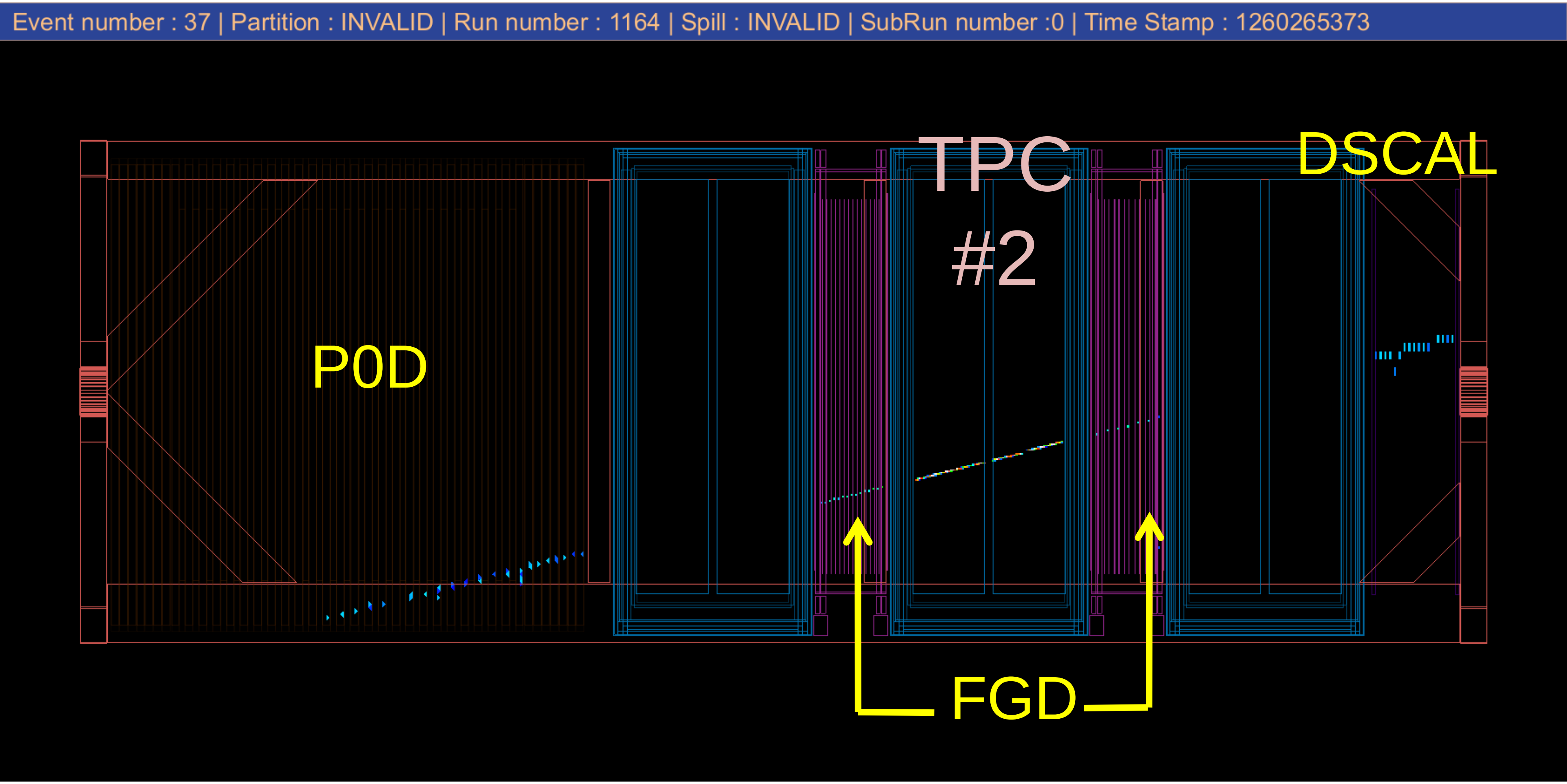


Top view of ND280



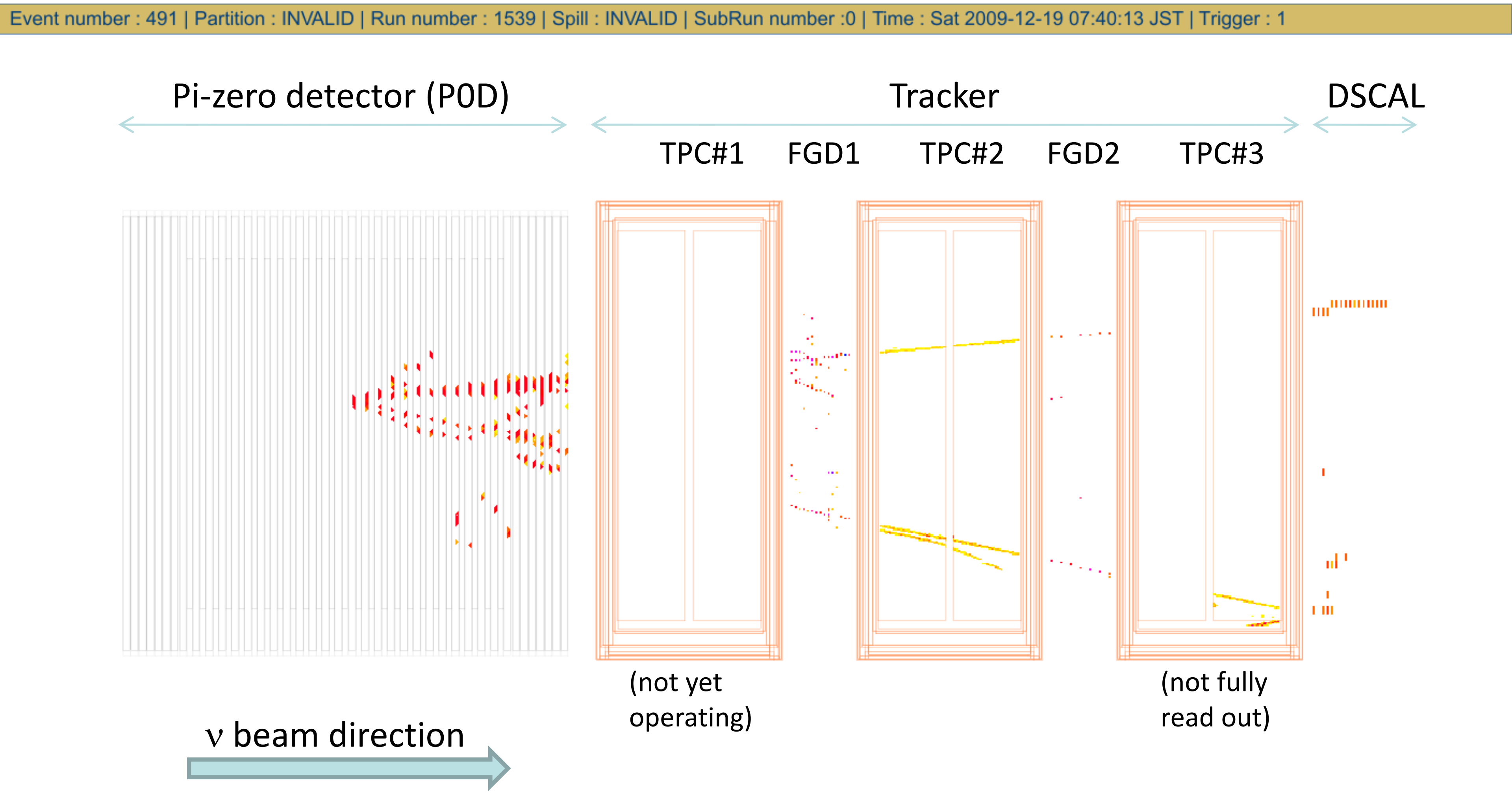
almost all sub-detectors are installed, commissioned and ready for beam

First tracks in ND280



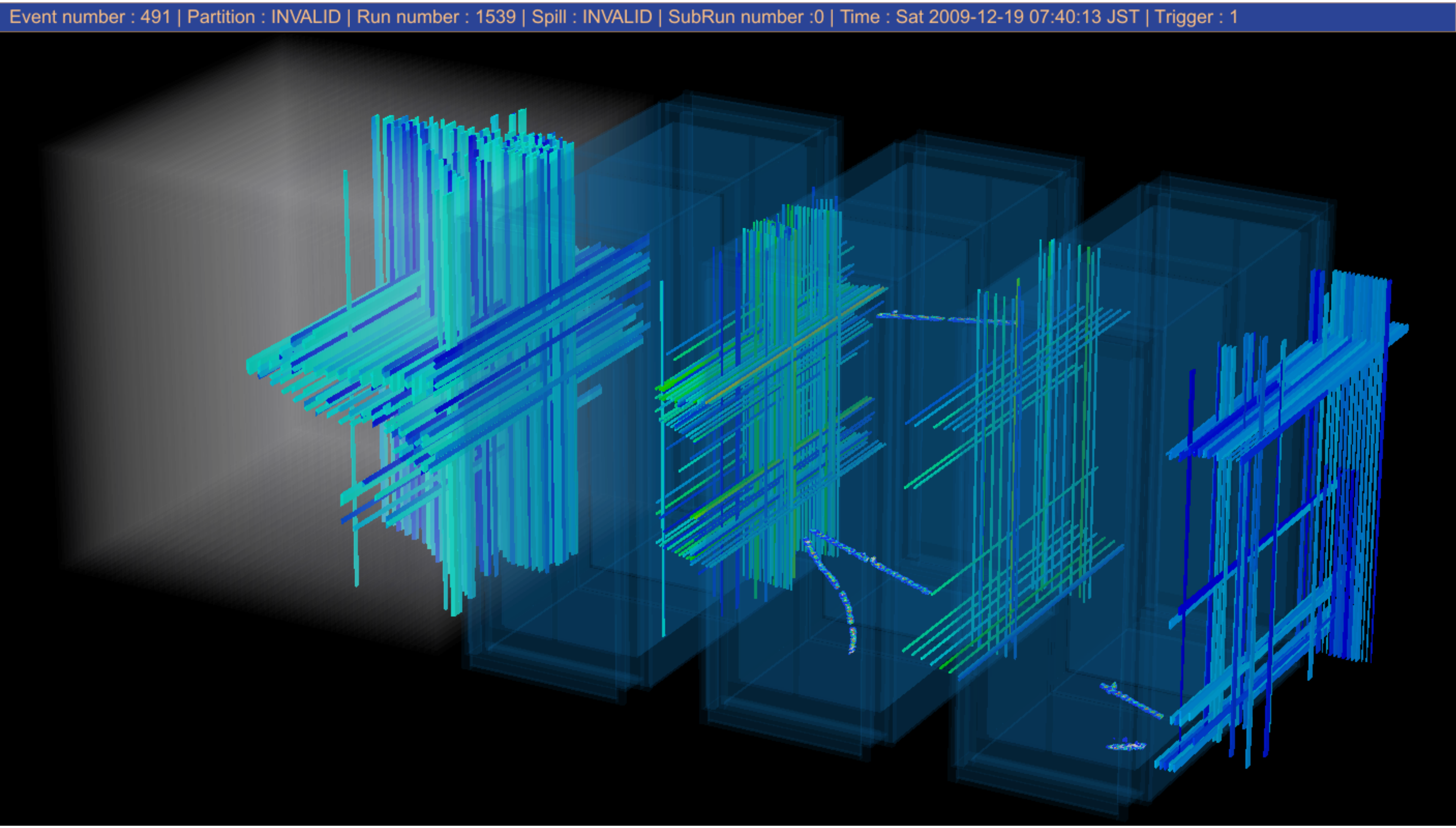
First ν event candidate in ND280

December 19, 2009

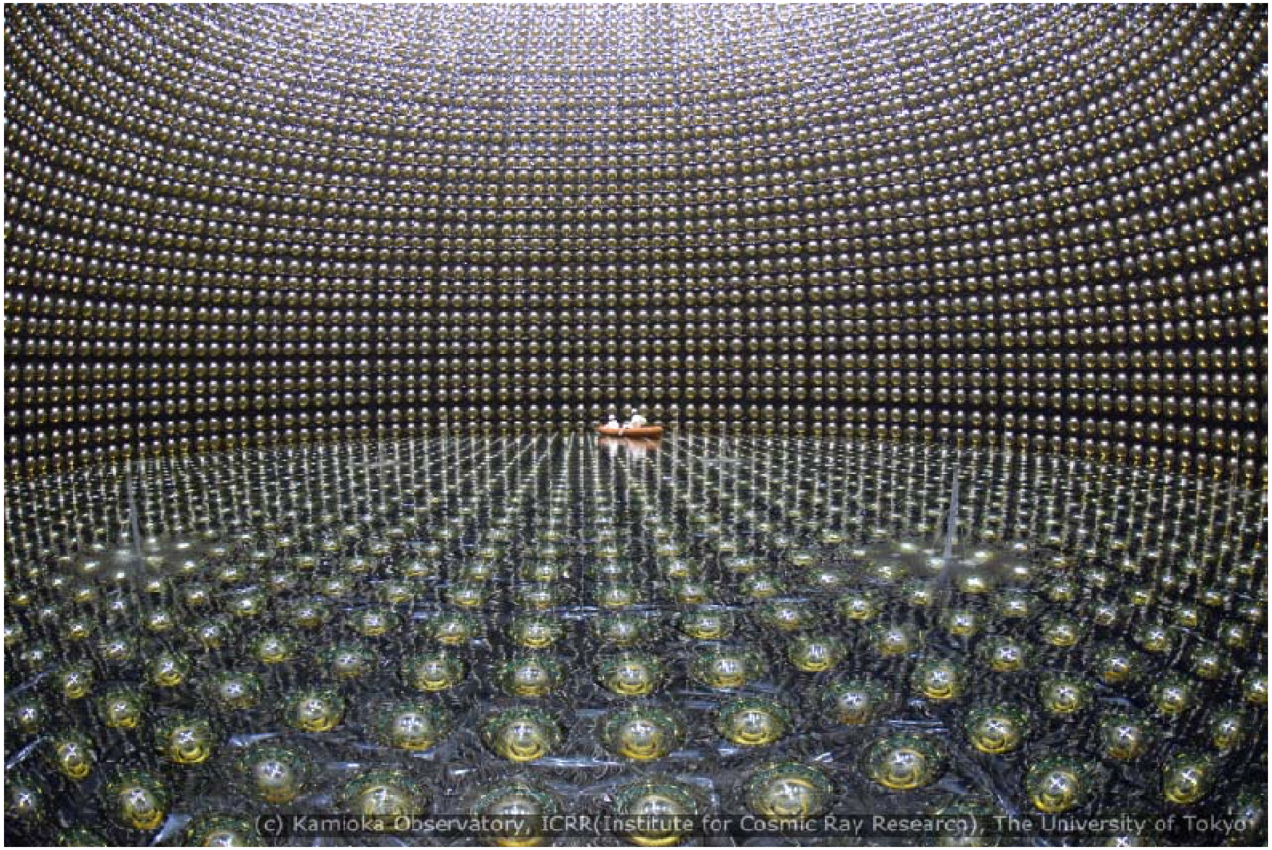


First ν event candidate in ND280

December 19, 2009



Far detector: Super-Kamiokande



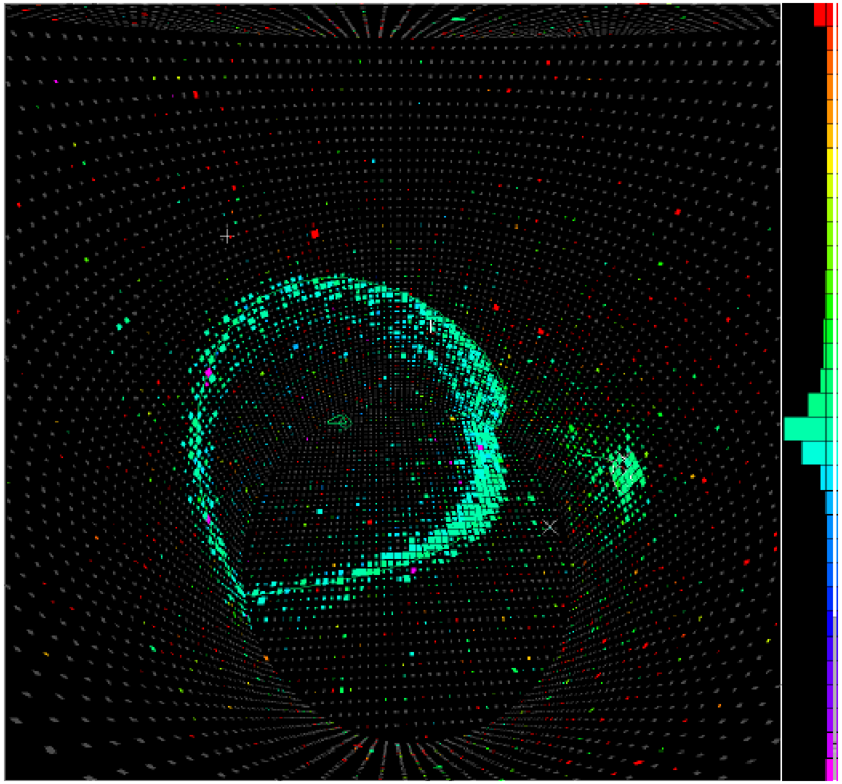
50 kt Water Cherenkov detector
(22.5 kt fiducial volume)
~11000 20” PMTs
~2000 anti counter PMTs

new electronics

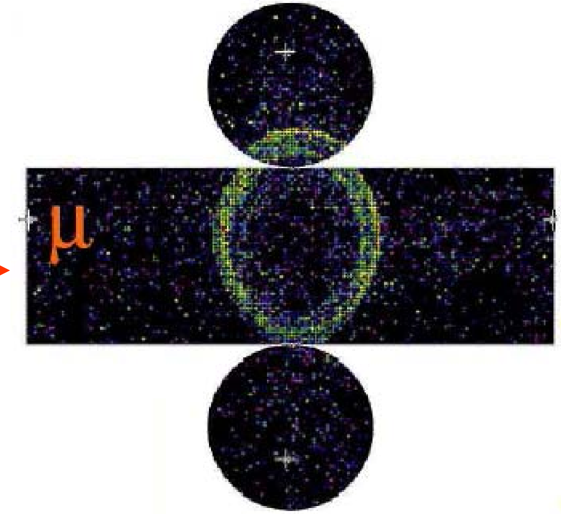
New electronics and DAQ installed in summer of 2008 (SK-IV)
dead-timeless DAQ $\rightarrow$ improvement of e tagging from μ decay

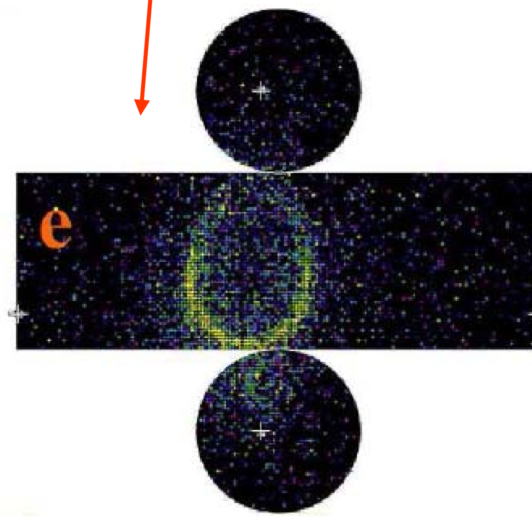
Super-Kamiokande is ready for T2K experiment

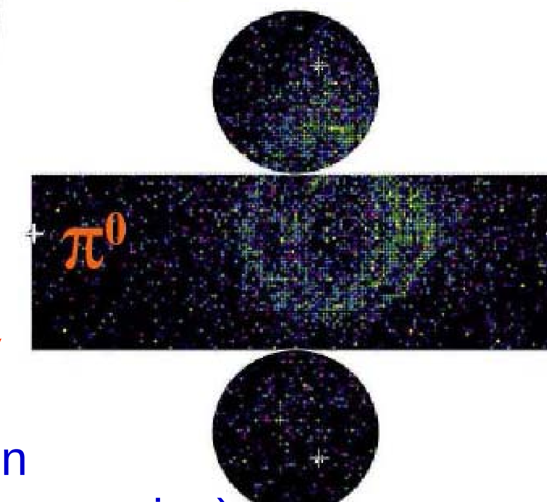
SK typical events



good $\mu - e$ separation







background for ν_e appearance:
- intrinsic ν_e component in initial beam
- merged π^0 rings from NC interactions

good π^0 rejection
(2 rings from γ conversion)

Sensitivity to θ_{13}

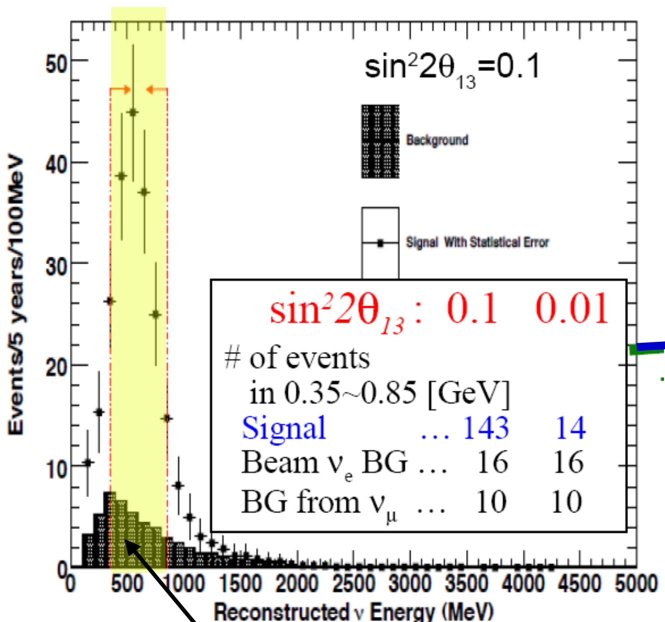
Detection of ν_e appearance: $\nu_\mu \to \nu_e$

T2K sensitivity (90%CL)

assuming $\sin^2\theta_{23} = 1$ and $\delta_{CP} = 0$

$\sin^2(2\theta_{13}) < 0.008$ (90% CL)

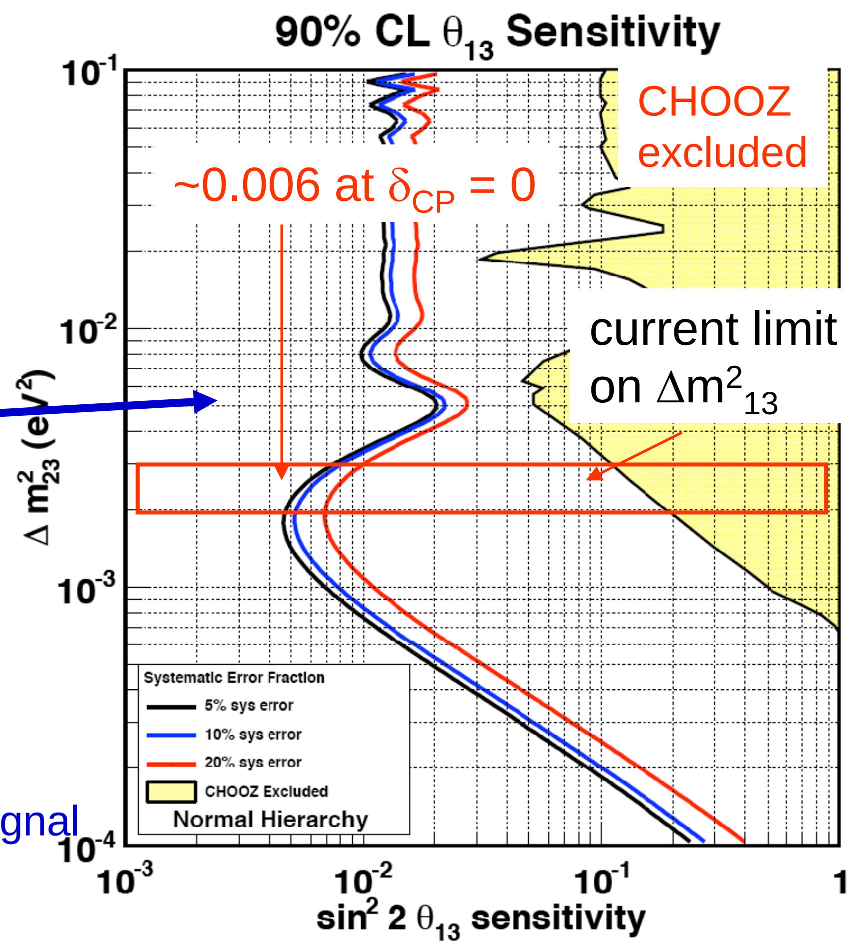
~ 5 years @ full (750 kW) intensity,
i.e. 8×10^{21} protons on target



background

+ sys. in background subtraction

- 5%
- 10%
- 20%



δ_{CP} term can enhance or suppress ν_e appearance signal

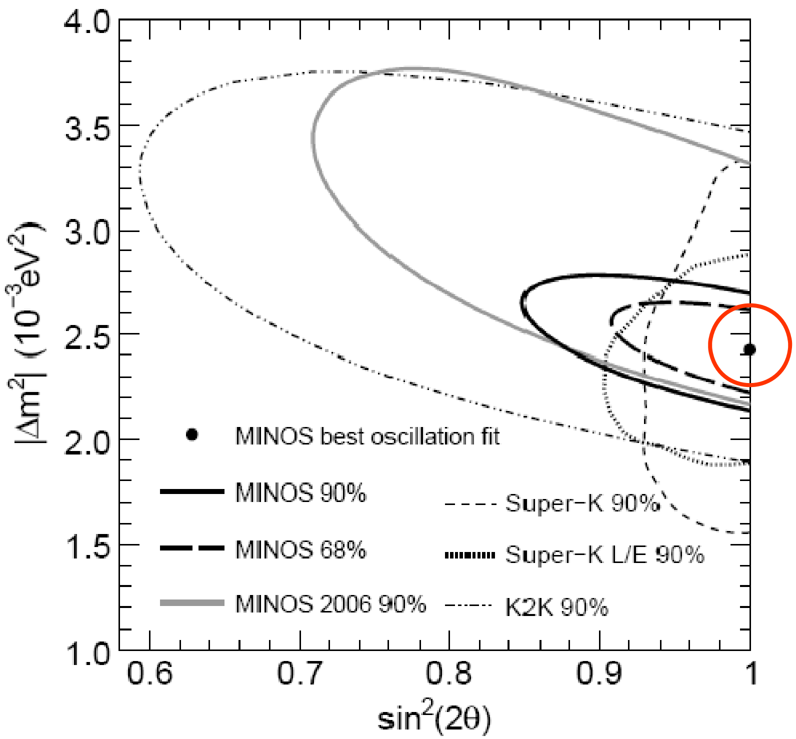
even if $\delta_{CP} = \pi/2$ (worst case scenario)
T2K is sensitive down to $\sin^2(2\theta_{13}) \sim 0.02$

Sensitivity to θ_{23} and Δm^2_{23}

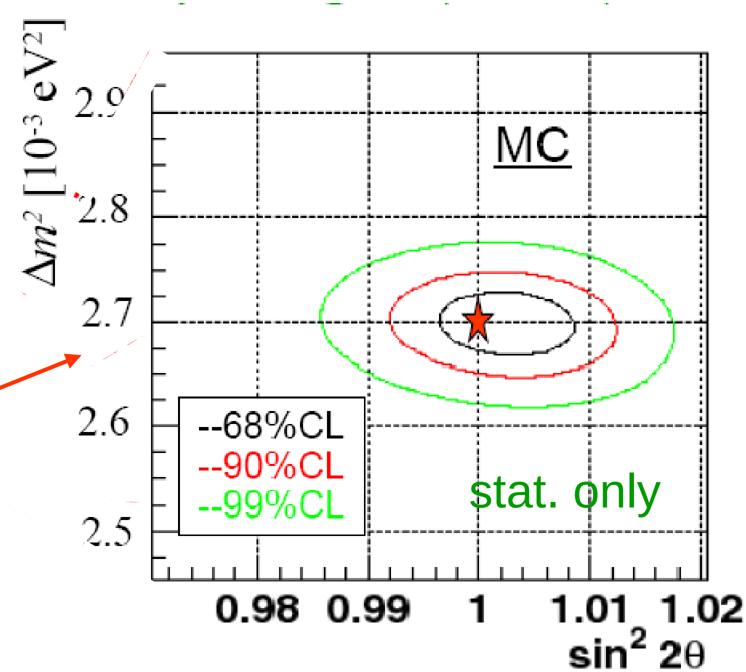
precise measurement of "atmospheric" ν parameters – ν_μ disappearance: $\nu_\mu \rightarrow \nu_x$

$\delta(\sin^2(2\theta_{23})) \sim 0.01$ $\delta(\Delta m^2_{23}) < 1\times10^{-4}\ \mathrm{ev}^2$ @90 CL

current status of "atmospheric" ν oscillation parameters ($\sin^2(2\theta_{23})$ and Δm^2_{23})



~ 5 years @ full (750 kW) intensity, i.e. 8×10^{21} protons on target



Outlook & 2010 goals

Beam commissioning completed

achieved stable operation at 20 kW
high intensity trial at 50 kW successful
working on increasing beam power to 100 kW (for the 2010 run)

Far Detector – Super-Kamiokande ready for T2K

ND280 detector installation almost completed

all sub-detectors being commissioned and
ready for beam
magnet closed last week
operation with magnetic field about to start

1st physics run is planned to start from March 2010
aim to accumulate 100 kW $\times$ 10^7 sec in 2010

In 2010 aim for better sensitivity on θ_{13}
than the current limit set by CHOOZ
(expect ~ 20 CCQE ν_μ events in SK
if $\sin^2(2\theta_{13})$ ~ 0.1 expect 3-4 ν_e in SK)