Status of the long baseline neutrino experiment T2K

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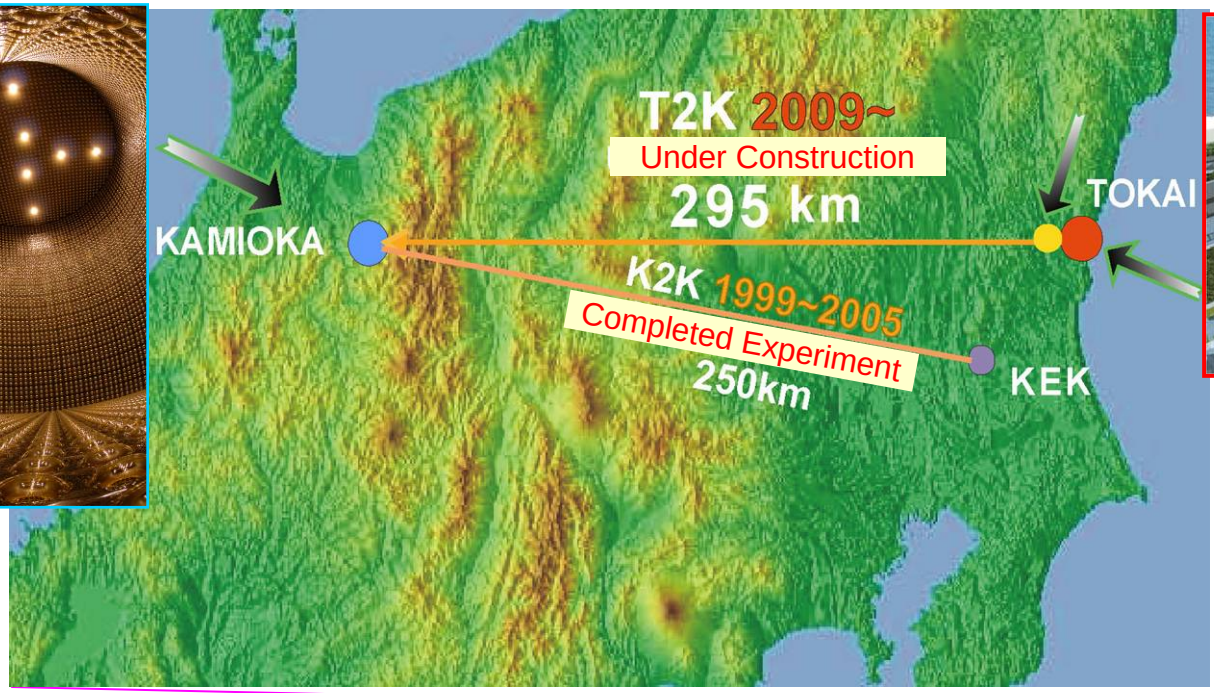
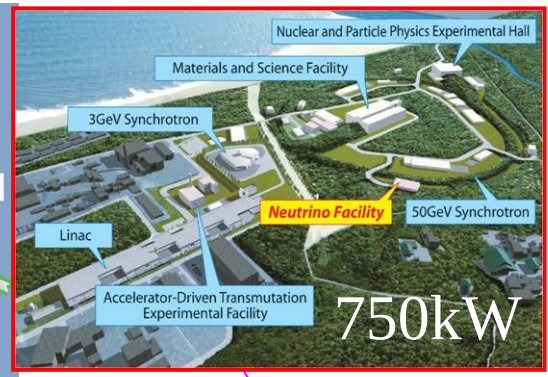
QUARKS2008, Sergiev Posad, Russia, 24 May 2008

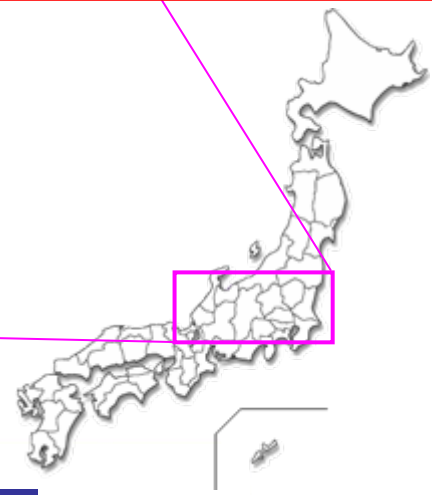
OUTLINE

- **Neutrino masses and mixings**
- **T2K physics**
- **Beam line**
- **Neutrino detectors**
- **Plan & Conclusion**

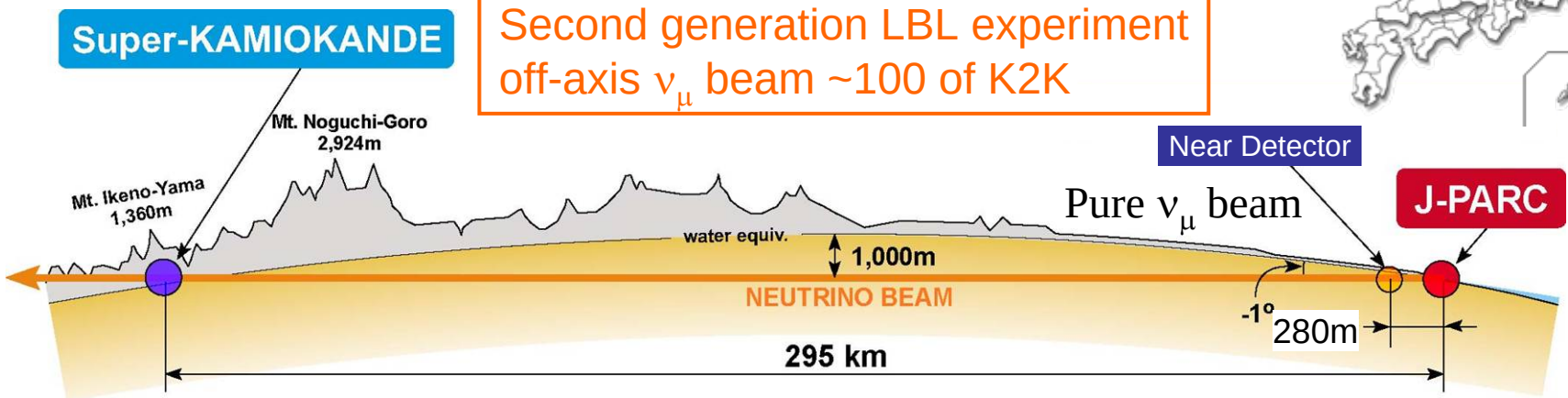
T2K (Tokai to Kamioka) LBL neutrino experiment







Second generation LBL experiment
off-axis ν_μ beam ~100 of K2K



T2K Collaboration

~400 collaborators from 12 Countries

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

T2K was approved in December 2003. Construction started in April 2004

Mixing matrix

3 families

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix} \qquad U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

atmospheric

solar

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

link between atmospheric and solar

***U* parameterization:** three mixing angles θ_{12} θ_{13} θ_{23}

CP violating phase δ

$$\Delta m^2_{ij} = m^2_i - m^2_j \qquad \Delta m^2_{12} + \Delta m^2_{23} + \Delta m^2_{31} = 0 \Rightarrow$$

two independent Δm^2

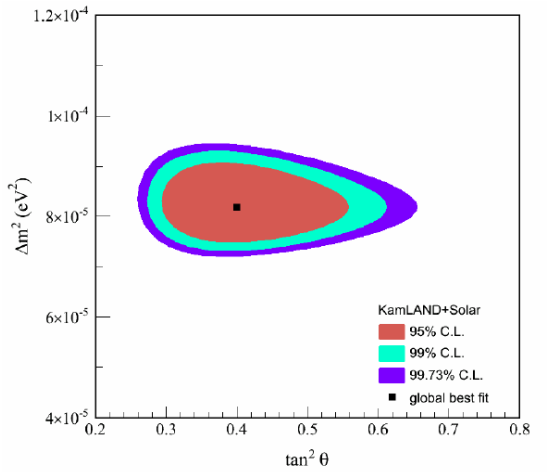
$$\Delta m^2_{12} = \Delta m^2_{sol} \qquad \Delta m^2_{23} \cong \Delta m^2_{31} = \Delta m^2_{atm}$$

Current status of masses and mixings

θ_{12}, Δm_{12}^2

$\Delta m^2_{solar} = 8 \times 10^{-5}$ eV^2

$\sin^2(2\theta_{12}) = 0.86$

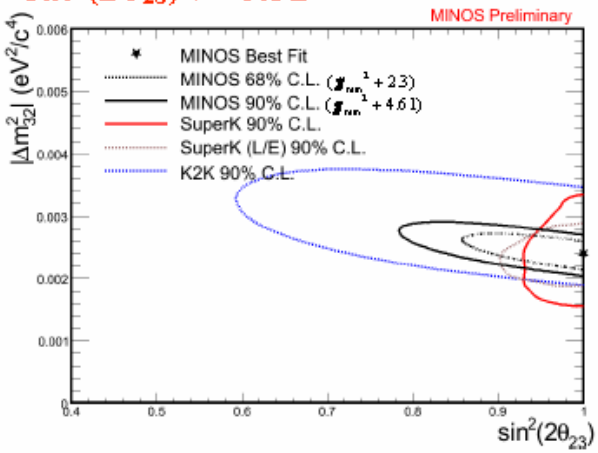


Solar + KamLAND

θ_{23}, Δm_{32}^2

$\Delta m^2_{atm} = (2.2\sim2.6) \times 10^{-3}$ eV^2

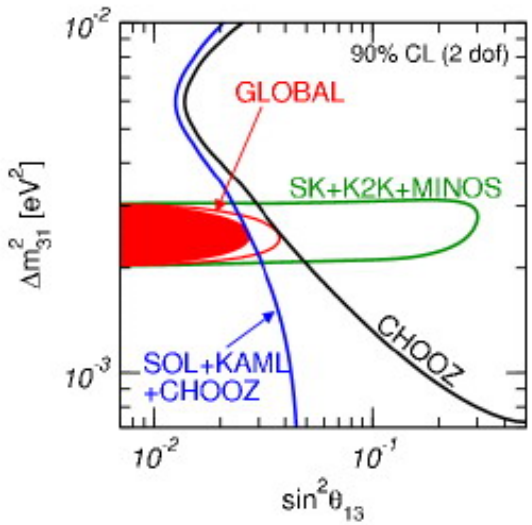
$\sin^2(2\theta_{23}) > 0.92$



SK + K2K + MINOS

θ_{13}, Δm_{31}^2

$\theta_{13} \leq 10^0$



Only upper limit on θ_{13}
No information about δ

Mixing and masses: q's and ν's

M.C.Gonzalez-Garcia, M.Maltoni, Phys.Rept.460:1-129,2008

Oscillation parameters

	central value	3σ interval
Δm^2_{12} (10^{-5} eV^2)	7.67	7.00 - 8.28
Δm^2_{31} (10^{-3}eV^2)	2.37	1.94- 2.83 (normal hierachy)
Δm^2_{31} (10^{-3}eV^2)	2.46	1.99- 2.88 (inverted hierachy)
θ_{12} (deg)	34.5	30.0 – 38.5
θ_{23} (deg)	42.3	34.6 - 53.6
θ_{13} (deg)	0.0	0.0 – 12.9

Global data from *solar, atmospheric, reactor, LBL accelerator experiments*

Mixing	Quarks	Leptons
1-2 θ_{12}	13°	34°
2-3 θ_{23}	2.3°	42°
1-3 θ_{13}	~ 0.5°	<13°

$$U_{CKM} = \begin{pmatrix} 1 & 0.2 & 0.005 \\ 0.2 & 1 & 0.04 \\ 0.005 & 0.04 & 1 \end{pmatrix} \qquad U_\nu = \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

Long baseline accelerator experiments

1st generation (on-axis ν beam): K2K, MINOS ($\nu_\mu \to \nu_\mu$) OPERA ($\nu_\mu \to \nu_\tau$)

2nd generation (off-axis ν beam): T2K, NOνA (proposal)

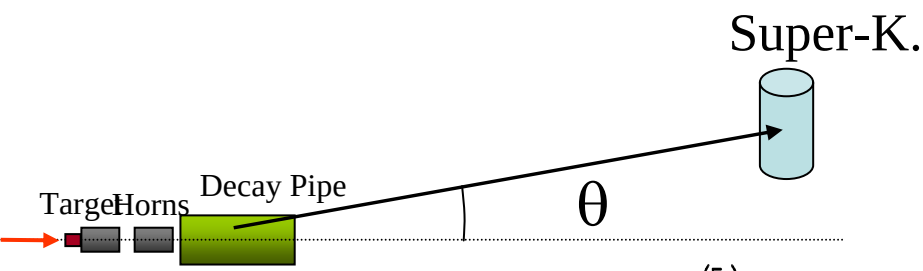
Main goals:

- **search for** $\nu_\mu \to \nu_e$ — θ_{13}
- **precise measurement** — Δm^2_{23} θ_{23}
- **mass hierarchy** — $\Delta m^2_{13} > 0$ **or** $\Delta m^2_{13} < 0$
- δ_{CP} — $\delta_{CP} \leftrightarrow \theta_{13}$ $U_{e3} = \sin\theta_{13} \exp(-i\delta_{CP})$

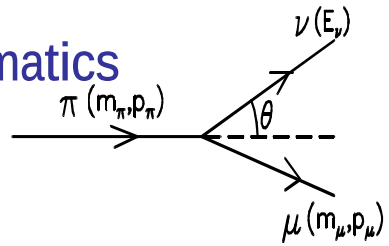
LBL experiments
cannot distinguish between Dirac and Majorana neutrinos
do not provide information about absolute ν mass

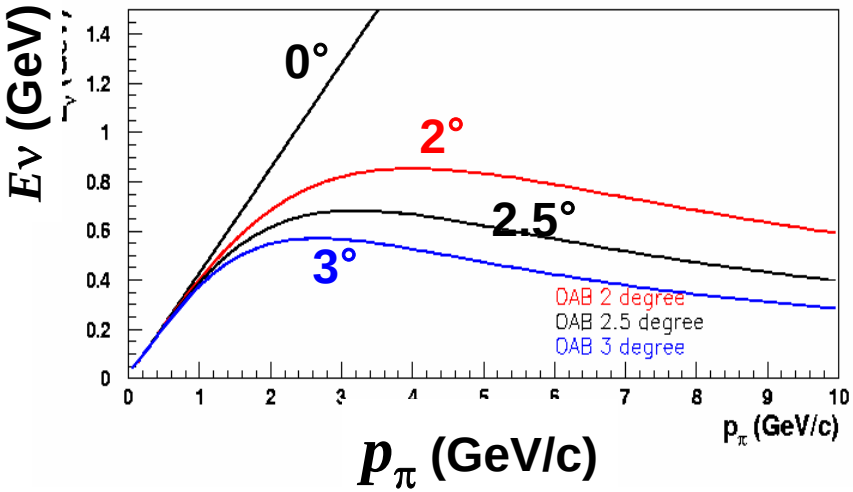
T2K: off-axis beam

	JPARC	MINOS	Opera	K2K
E(GeV)	50	120	400	12
Int(10^{12} ppp)	330	40	24	6
Rate (Hz)	0.29	0.53	0.17	0.45
Power (MW)	0.75	0.41	0.5	0.0052

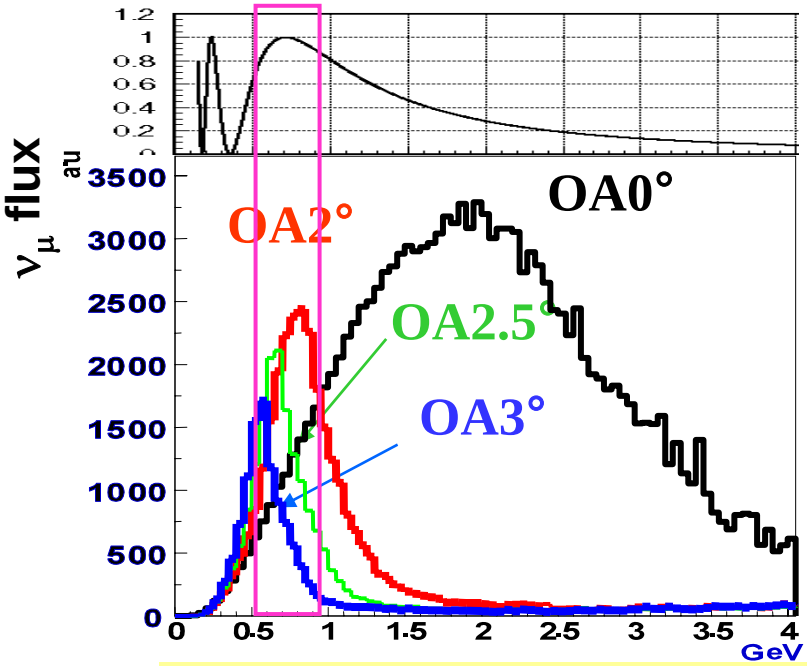


π decay Kinematics





p_π (GeV/c)



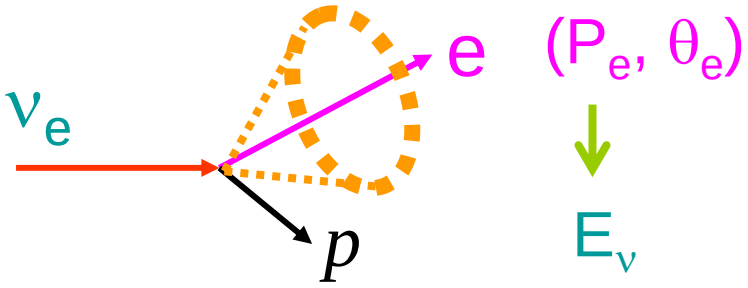
- Quasi Monochromatic Beam
- 2-3 times intense than NBB
- Tuned at oscillation maximum

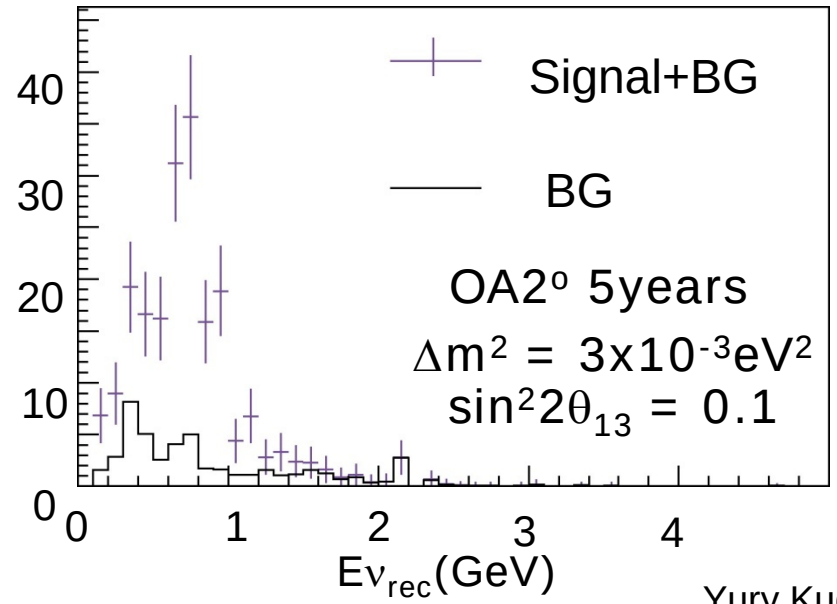
Statistics at SK
(OAB 2.5 deg, 1 yr, 22.5 kt)
~ 2200 ν_μ tot
~ 1600 ν_μ CC
ν_e ~0.4% at ν_μ peak

Principle T2K goal (1): $\nu_\mu \rightarrow \nu_e$

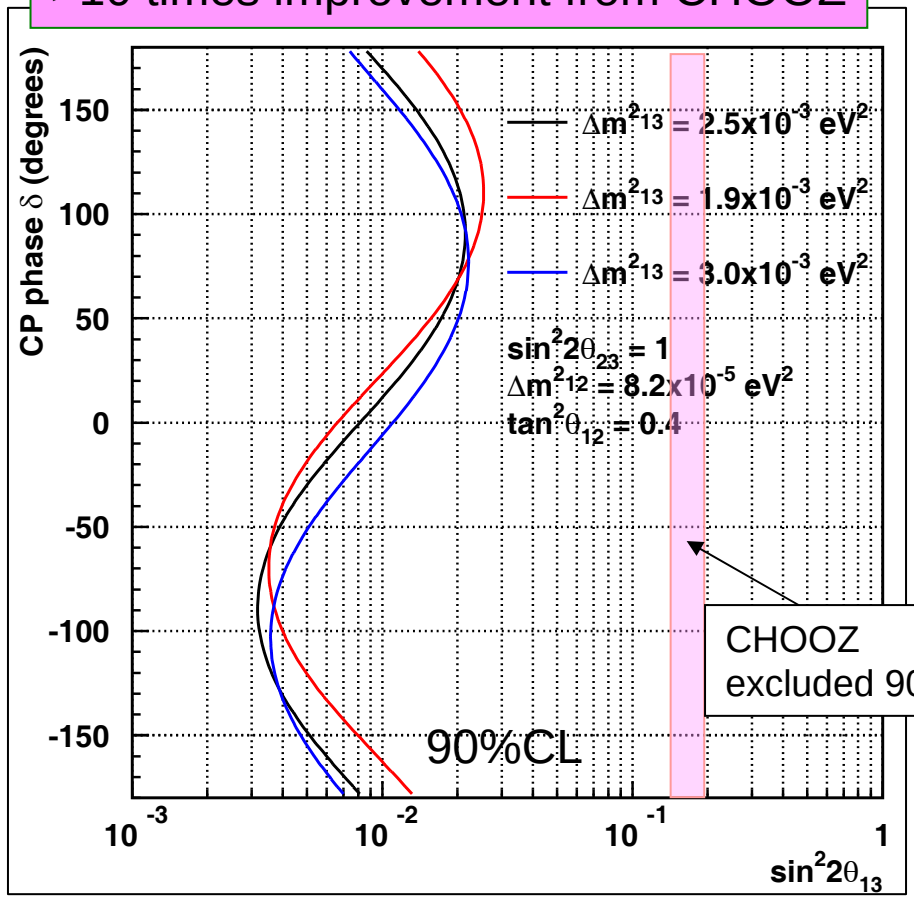
Discovery of ν_e appearance (θ_{13})

Search for CP violation
In lepton sector





>10 times improvement from CHOOZ



ν_e appearance

- Look for excess events in 1-ring e-like sample at SK

Expected number of events at SK (0.75kW beam x 5years = 5×10^{21}pot)

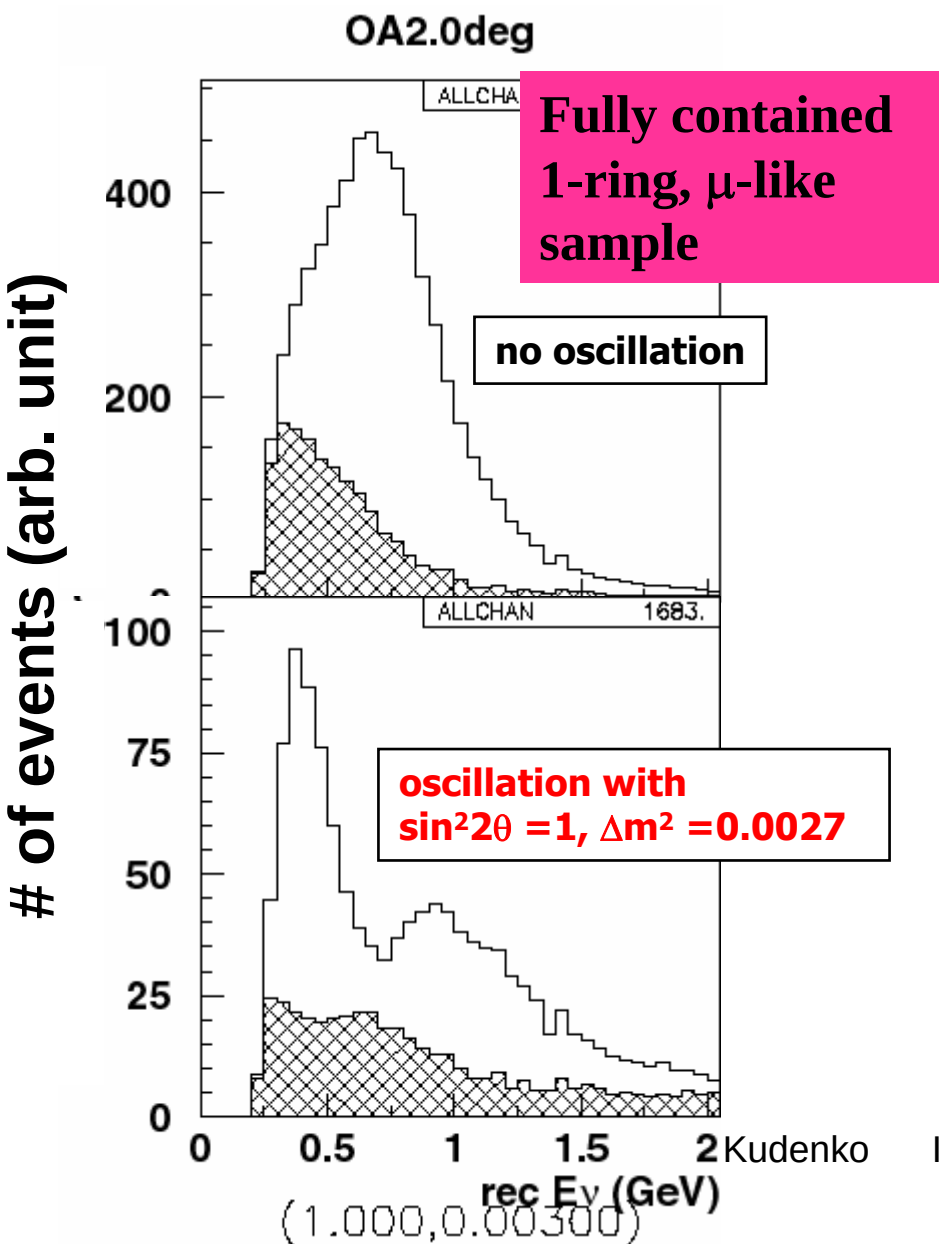
$\sin^2 2\theta_{13}$	Backgrounds			Signal
	ν_μ induced	Beam ν_e	Total	
0.1	10	13	23	103
0.01				10

- Dominant background sources:
  - Beam ν_e contamination
    - Irreducible
  - Neutrino-induced NC1π^0 events
    - one of 2γ's from π^0 is missed
    - Reducible, needs knowledge of NC1π^0 interaction

→ To be measured by Near Detector

Principle T2K goal (2): $\nu_\mu \rightarrow \nu_\mu$

Reconstructed ν spectra at SK

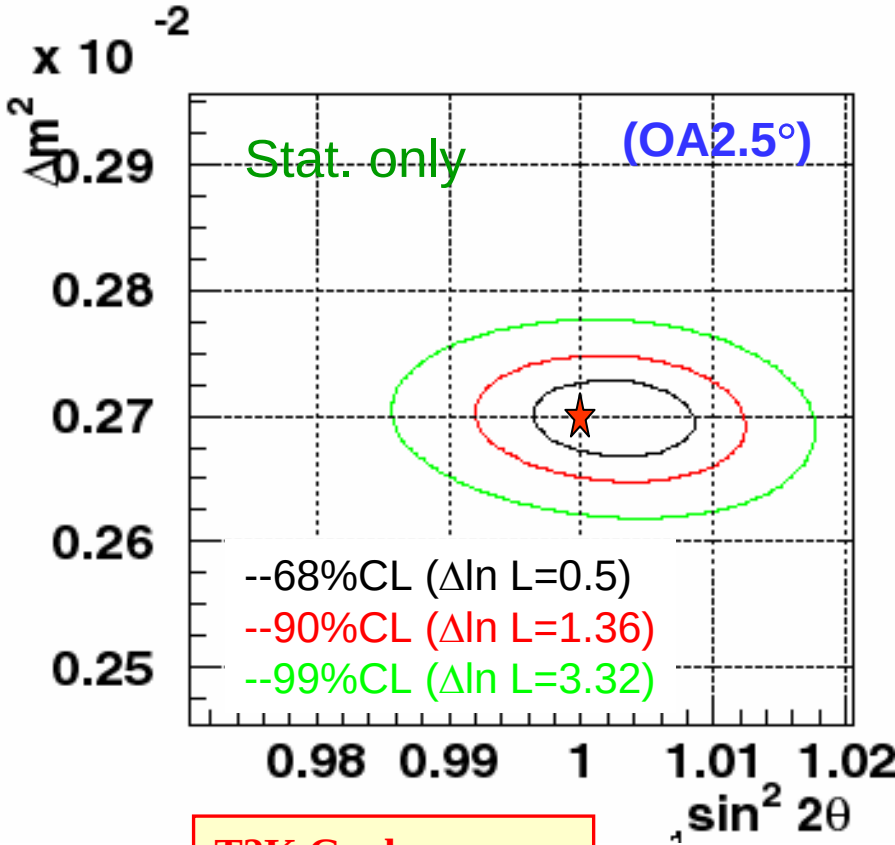


Fully contained 1-ring, μ-like sample

no oscillation

oscillation with $\sin^2 2\theta = 1$, $\Delta m^2 = 0.0027$

ν_μ disappearance

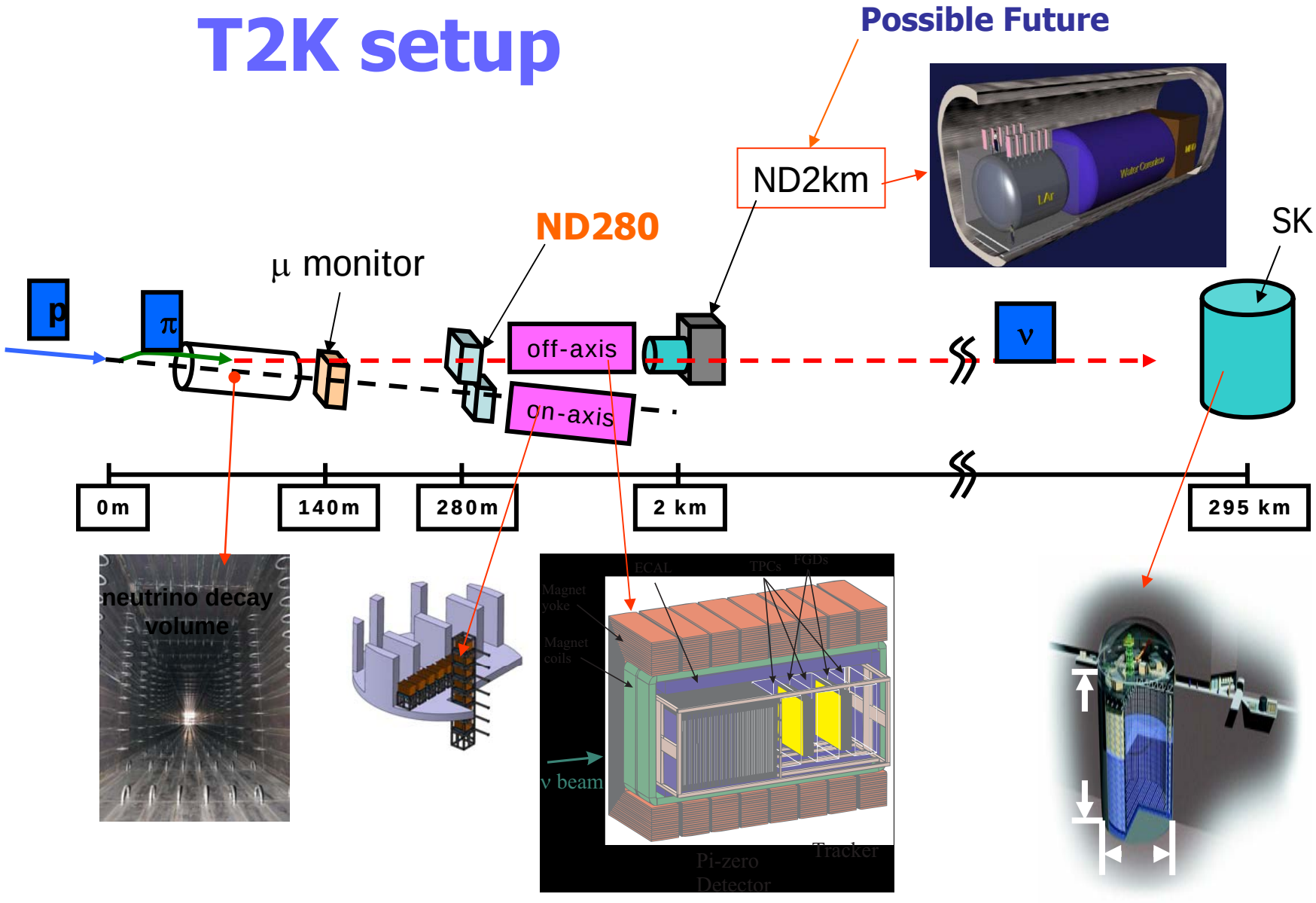


T2K Goal:

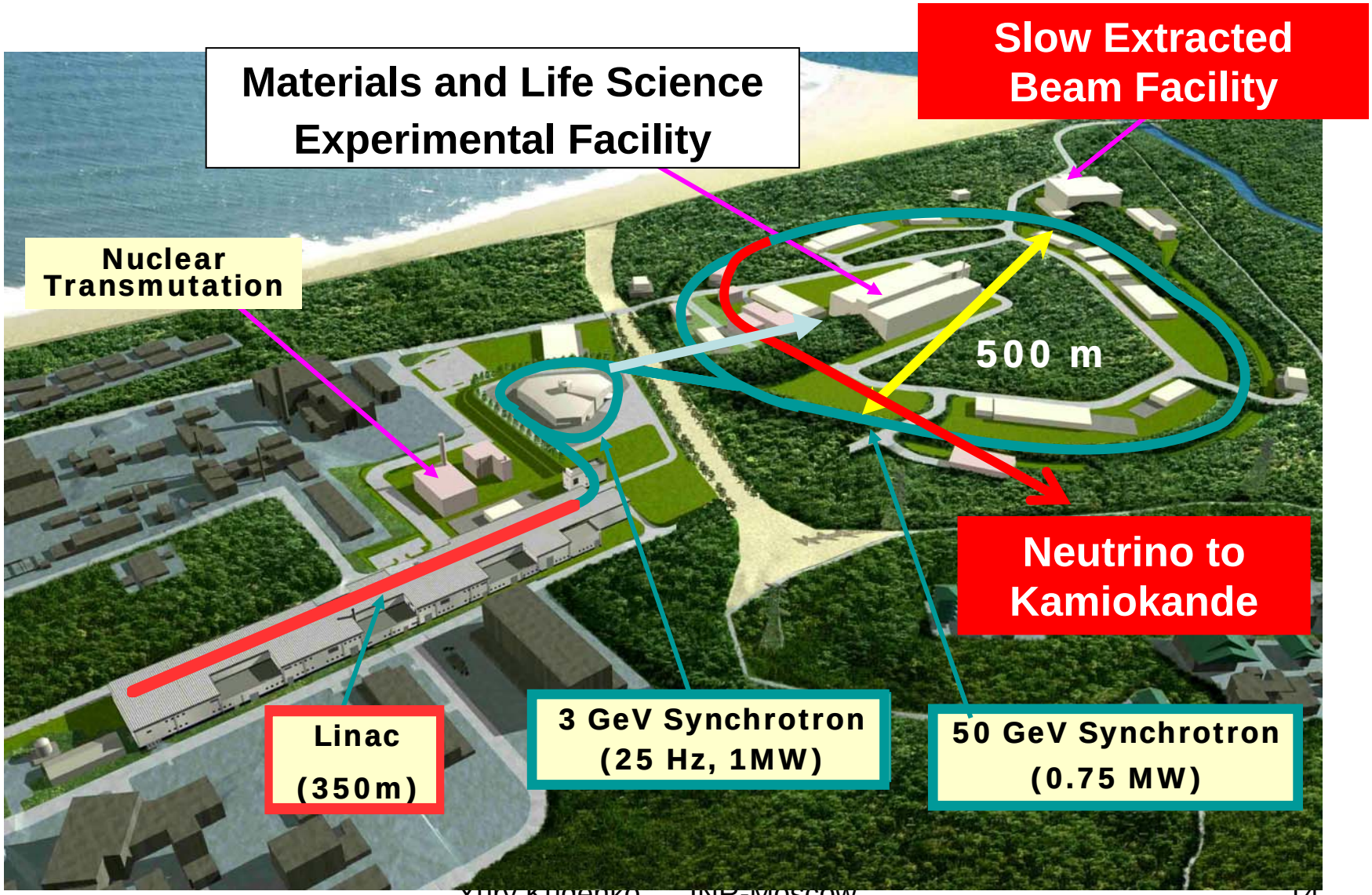
$\delta(\sin^2 2\theta_{23}) \sim 0.01$

$\delta(\Delta m^2_{23}) \sim 1\times10^{-4}$

T2K setup


Possible Future
ND2km
ND280
μ monitor
SK
p
π
off-axis
on-axis
ν
0m
140m
280m
2 km
295 km
neutrino decay volume
ECAL
TPCs
FGDs
Magnet yoke
Magnet coils
ν beam
Pi-zero Detector
Tracker

JPARC


Slow Extracted Beam Facility
Materials and Life Science Experimental Facility
Nuclear Transmutation
500 m
Neutrino to Kamiokande
Linac (350m)
3 GeV Synchrotron (25 Hz, 1MW)
50 GeV Synchrotron (0.75 MW)

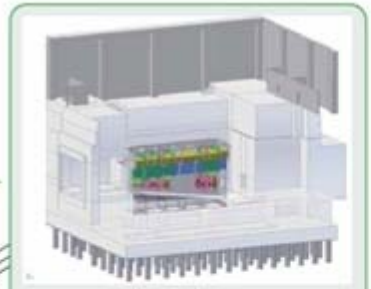
Status of JPARC accelerators

Main Ring :
50 GeV (initially 30 GeV)
0.75MW → $1x10^{21}$pot/year

- **LINAC:** successfully commissioned
  - 181 MeV achieved in January 2007
- **3 GeV Synchrotron (RCS):** successfully commissioned
  - 3 GeV acceleration and extraction achieved in October 2007
  - 4.6×10^{12} particles accelerated with 25 Hz (1 bunch)
- **50 GeV Synchrotron Main Ring:**
  - Installation of accelerator components and vacuum system completed
  - Commissioning just started in May 2008
  - Aim to accelerate to 30 GeV in Dec. 2008
  - Fast extraction to neutrino beamline in Apr. 2009

Neutrino Facility at JPARC

Target-Horn System



Target Station

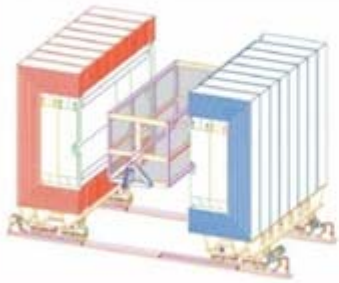
Preparation Section

Muon
Monitoring Pit

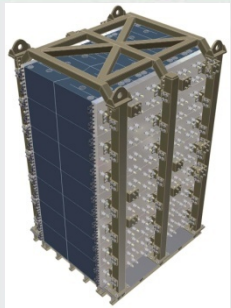
Final
Focusing
Section

295km to
Super-Kamiokande

110m



Near Neutrino Detector



Beam Dump

Decay Volume

SC combined func mags

Primary proton beam line

superconducting magnets

Arc section

normal conducting magnets

Preparation section

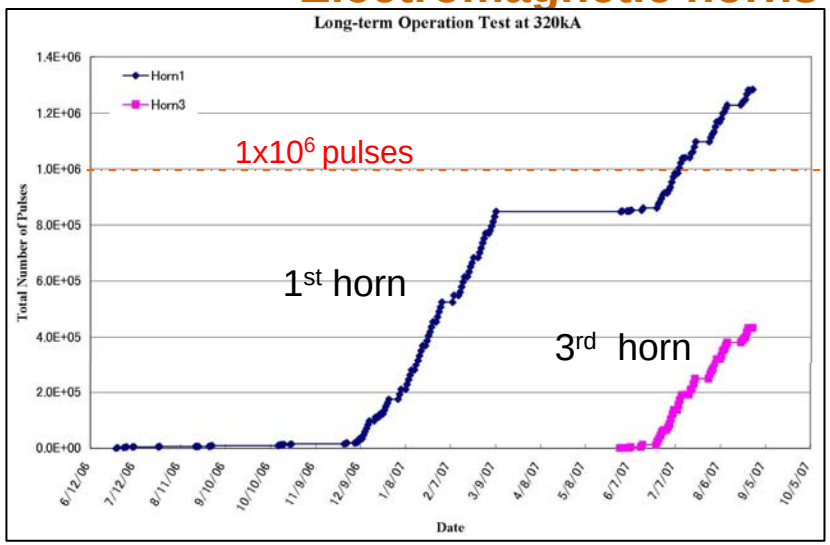
construction will be completed by December 2008

Target and horns

Target

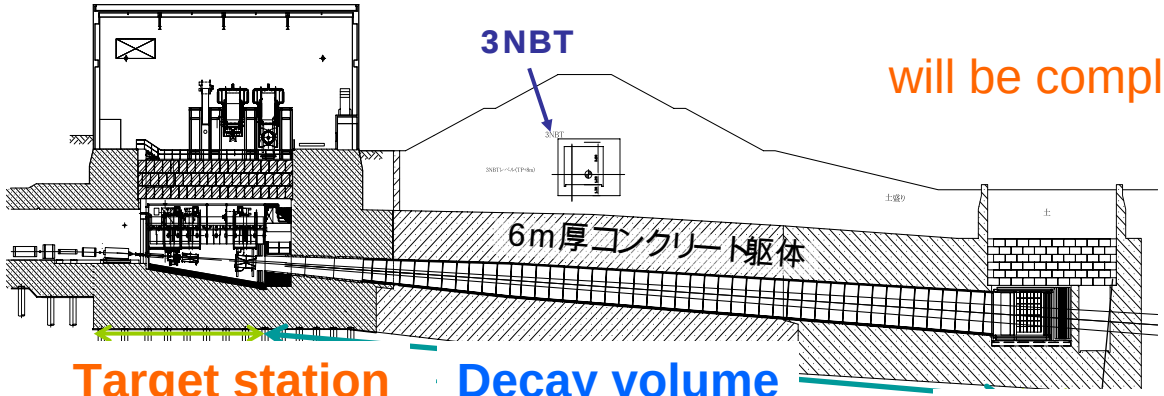
- graphite core: 26 mm (D) x 900 m (L)
- forced flow helium gas cooling in Ti-alloy capsule

Electromagnetic horns



assembly/installation will start in August 2008

Secondary beam line

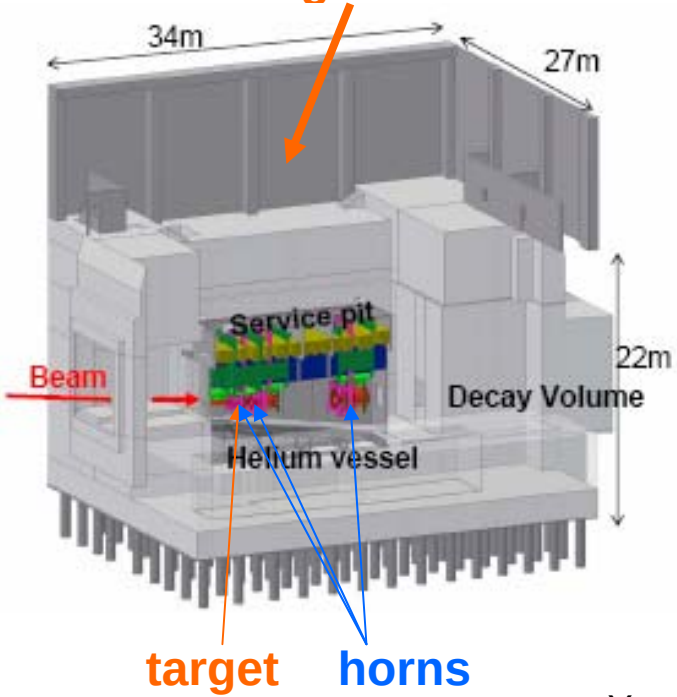


will be completed in October 2008

Target station

Decay volume

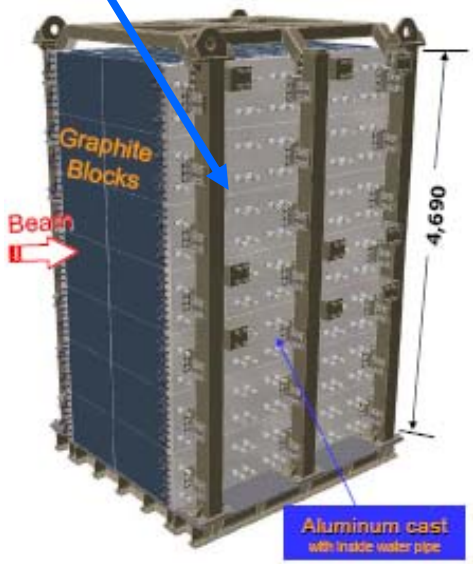
Beam dump



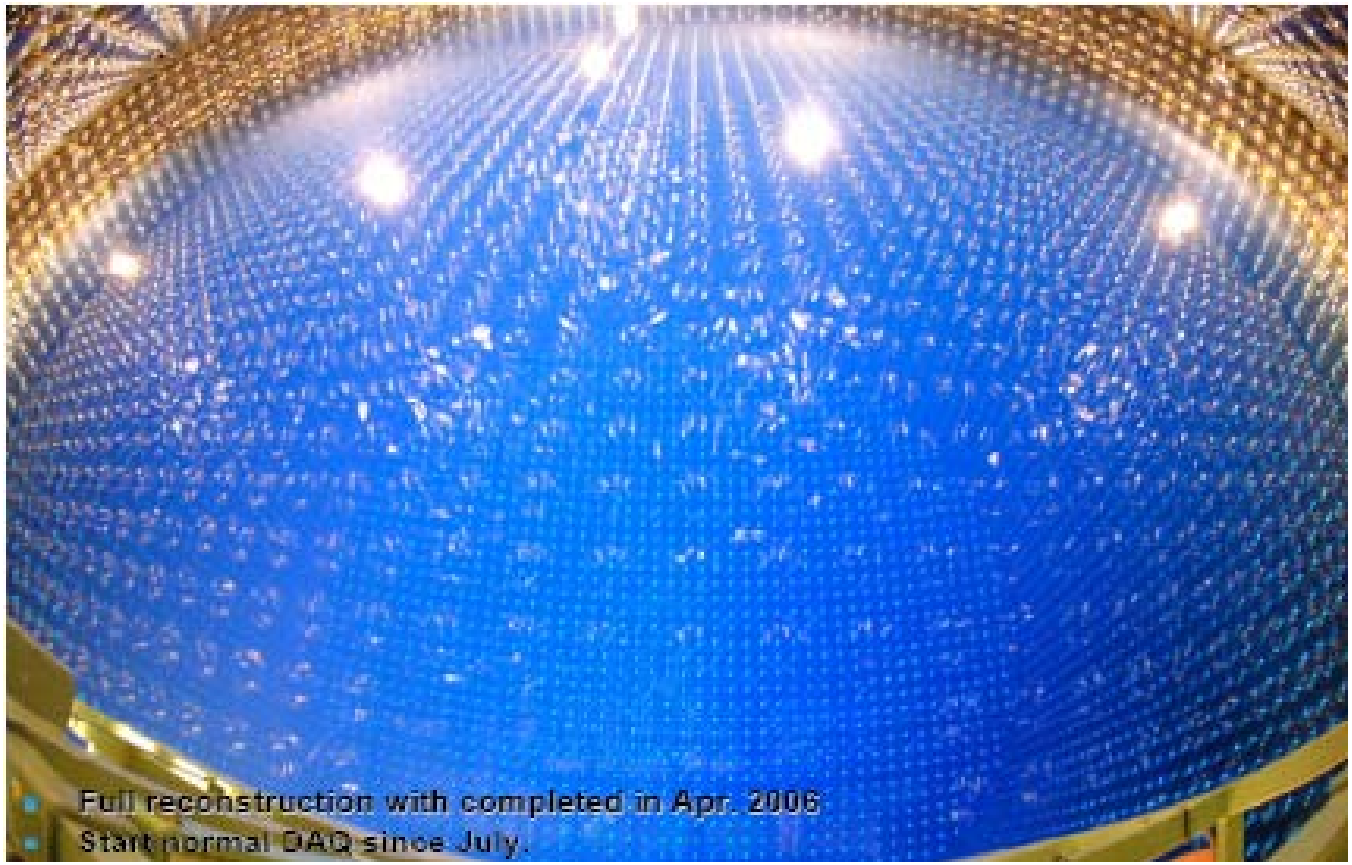
target

horns

Downstream part

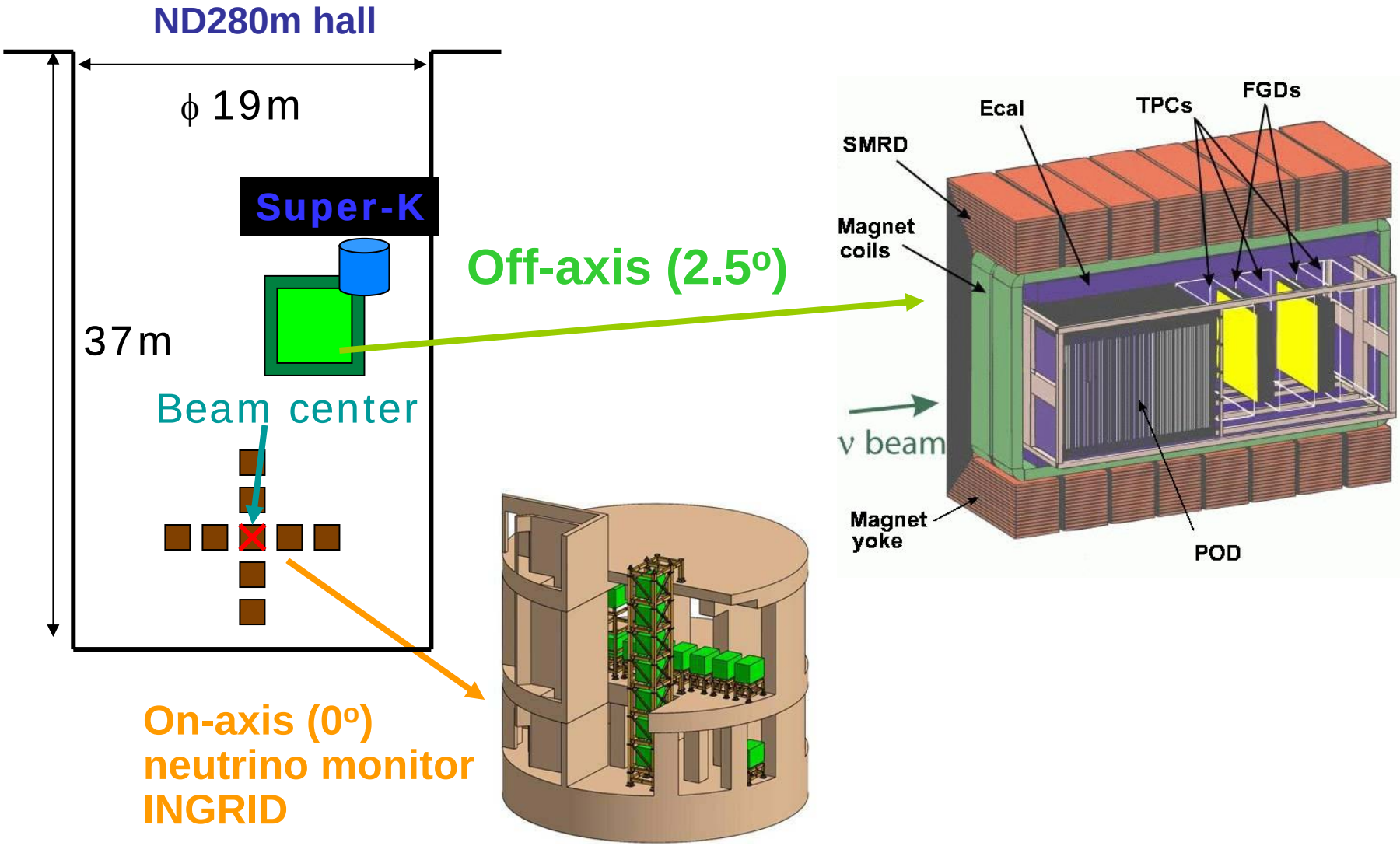


T2K far detector: SK-III



Completely reconstructed in April 2006
Data taking since Summer 2006

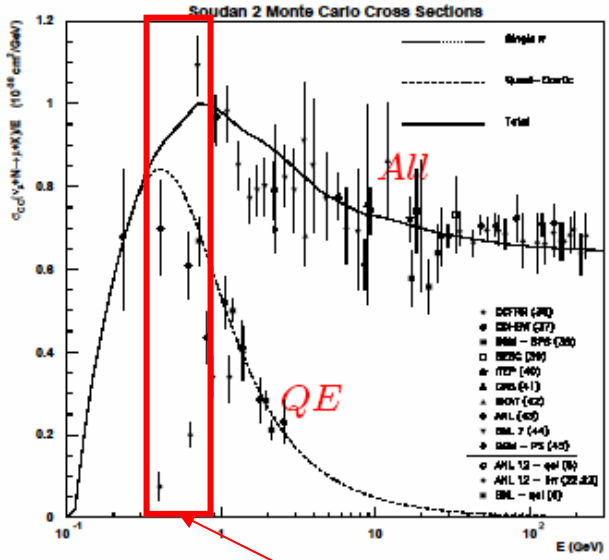
Near Detectors at 280m



Cross sections

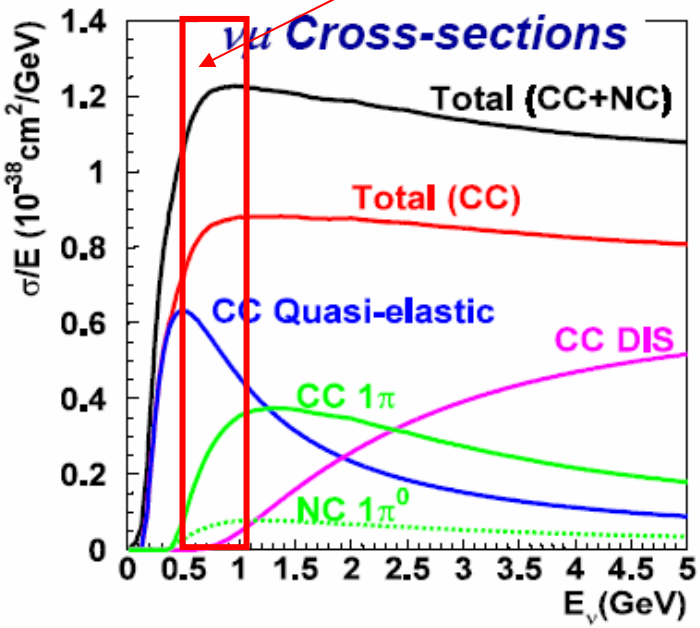
At ν energies 0.5-1.0 GeV absolute cross sections (CCQE) are measured with accuracy of 20-30%

Non-CCQE, 1π… much worse



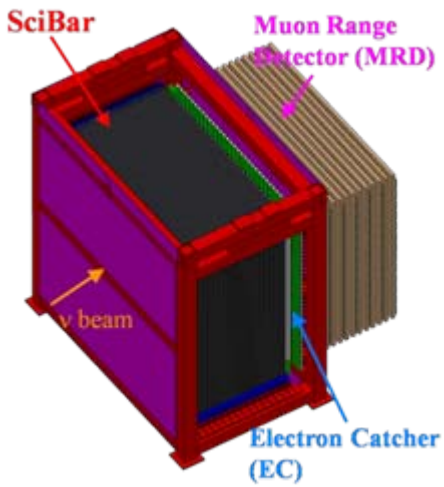
T2K neutrino energies

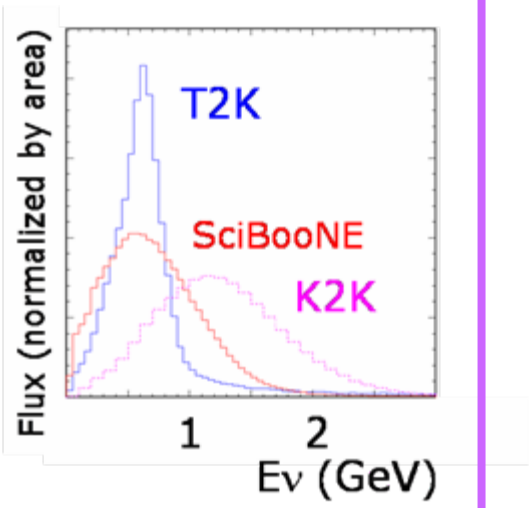
Measurement of ν cross sections by ND280 is critical for T2K

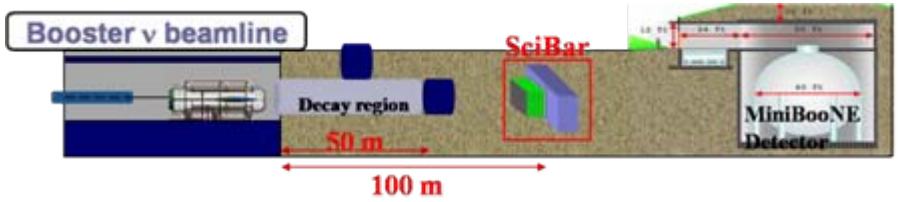


SciBooNe and NA61

SciBooNE at FNAL







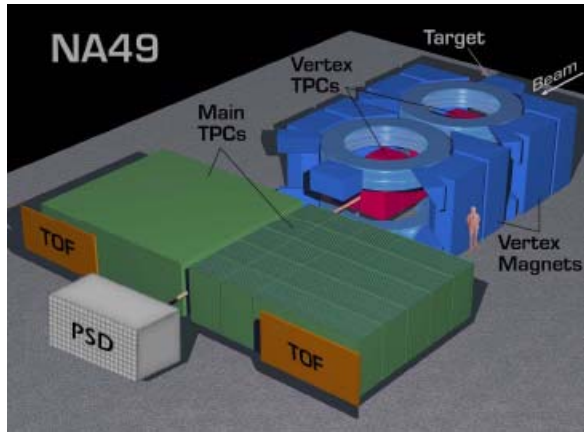
ν cross section at sub GeV (~T2K) energies

Collected 1. 46x10^{20} pot

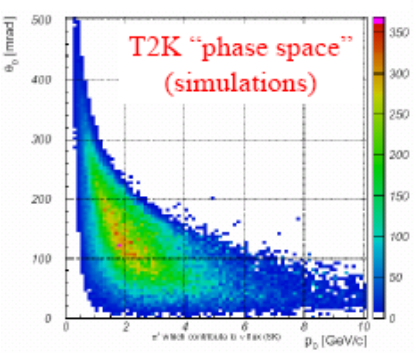
ν: 9.2x10^{19} (goal: 1x10^{20})

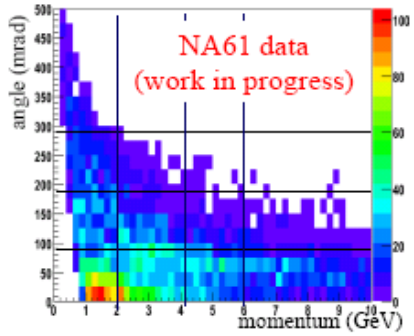
anti-ν: 5.4x10^{19} (goal: 1x10^{20})

NA61(CERN): measurement of hadron production at JPARC energies



NA49 detector with some upgrade





First data taking Oct. 2007 (1 month)

thin target (2cm thick)

T2K replica target (90cm)

Data analysis in progress

ND280 hall

ND280 pit excavated

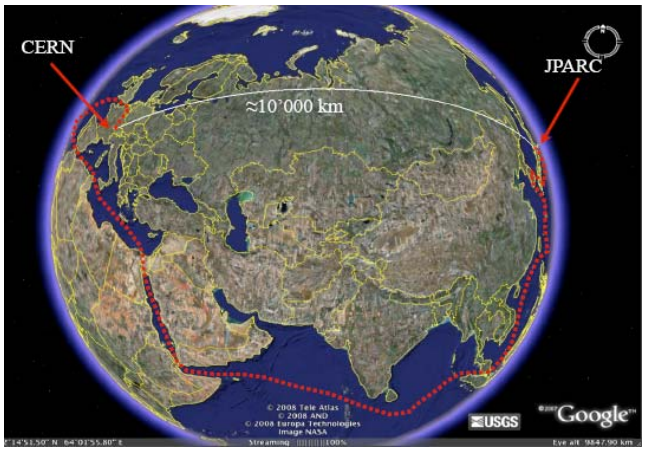
Carriages in the ND280 pit

UA1/NOMAD magnet

Refurbished at CERN in 2007

Shipped from CERN to JPARC in March 2008

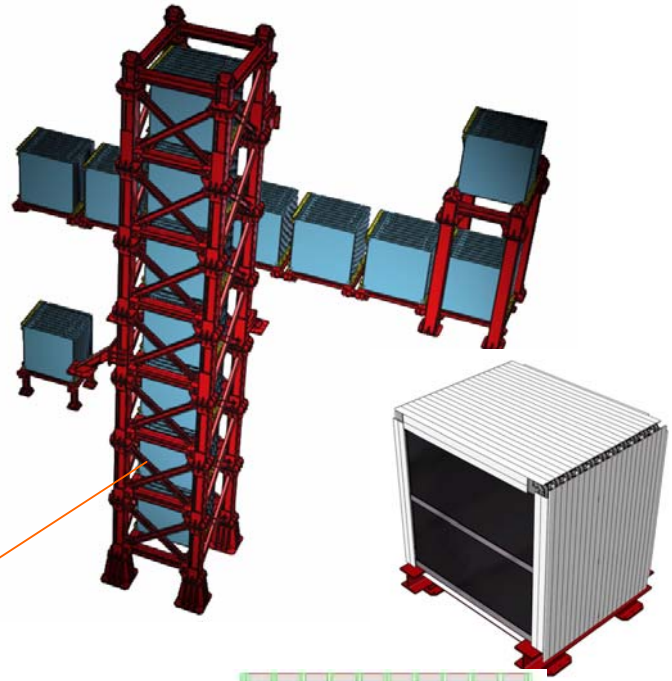
Assembly at JPARC area to be completed in June 2008

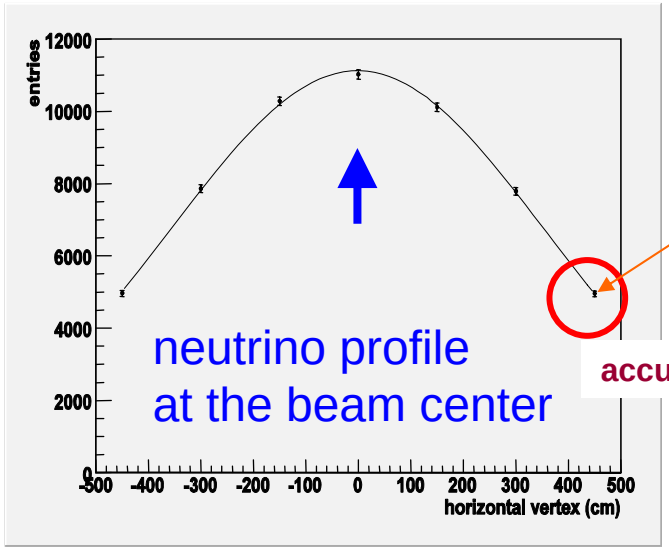


device for B-field measurement

On-Axis Neutrino Monitor (INGRID)

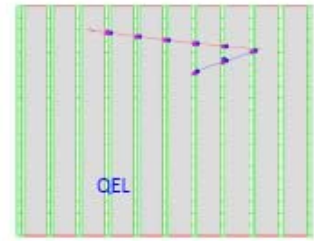
- **Monitor the neutrino beam**
  - **Direction**
  - **Profile**
  - **Intensity (& Energy)**
- **Iron-Scintillator sandwich detector:** **16 modules**
- **Each module consists of**
  - **10 Iron layers**
  - **11 layers of extruded scintillator strips 1x5x100 cm³**
  - **4 side veto planes**
  - **WLS fibers, Kuraray Y11**
  - **MPPC photosensor**

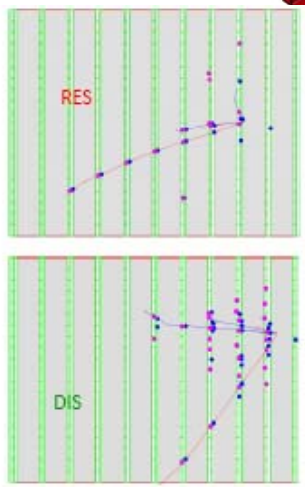




Event Rate/module

accuracy ~ 0.18 mrad

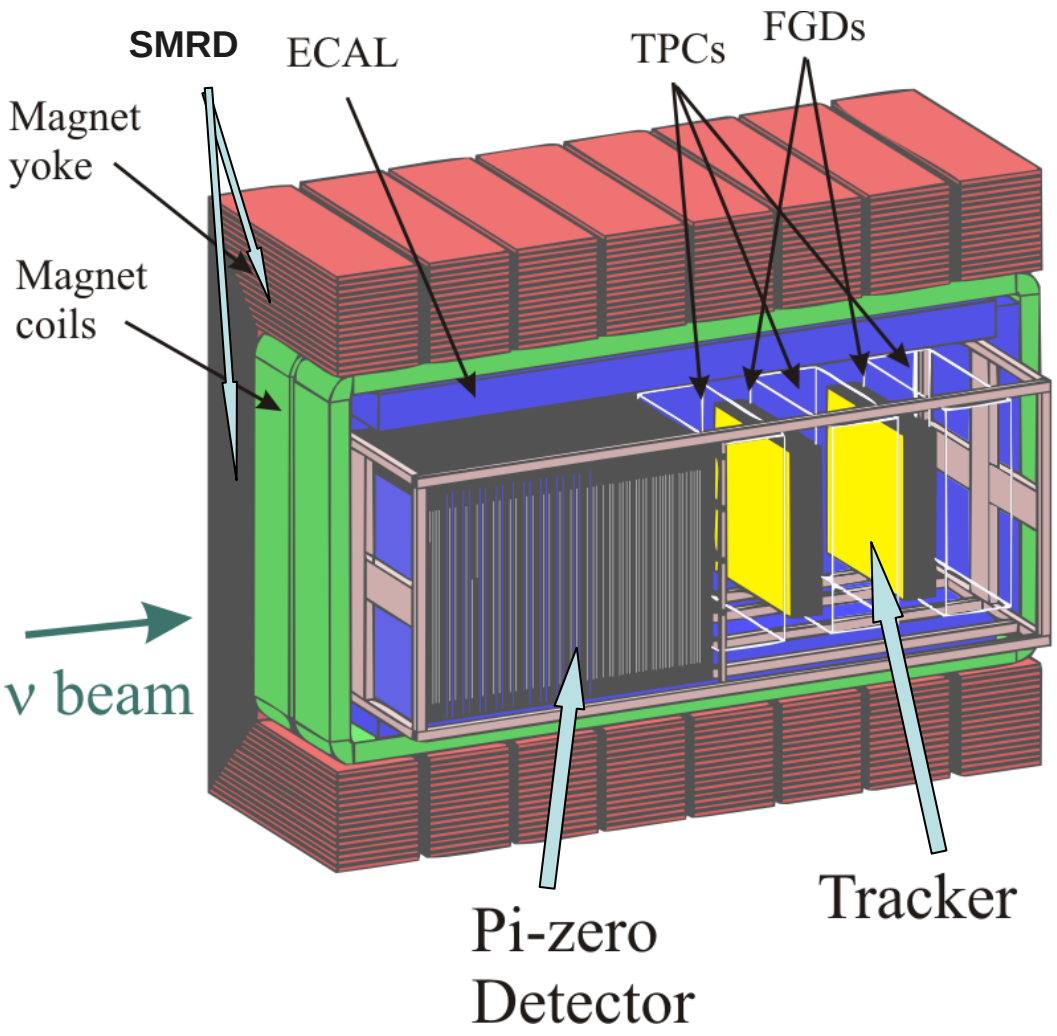




ND280m off-axis detector

- UA1 magnet
  0.2 T
  inner volume:
  $3.5 \times 3.6 \times 7.0\ m^3$

- Pi-Zero optimized for π^0 from NC
- Tracker optimized for CC studies
- surrounded by ECAL and Side Muon Range Detector



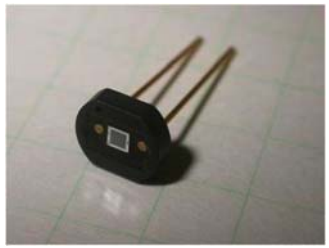
T2K photosensors

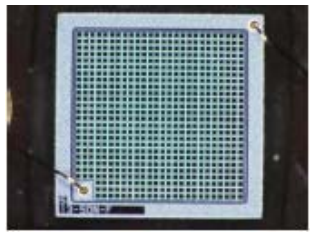
Most of ND280 active elements
scintillator detectors
with WLS fibers

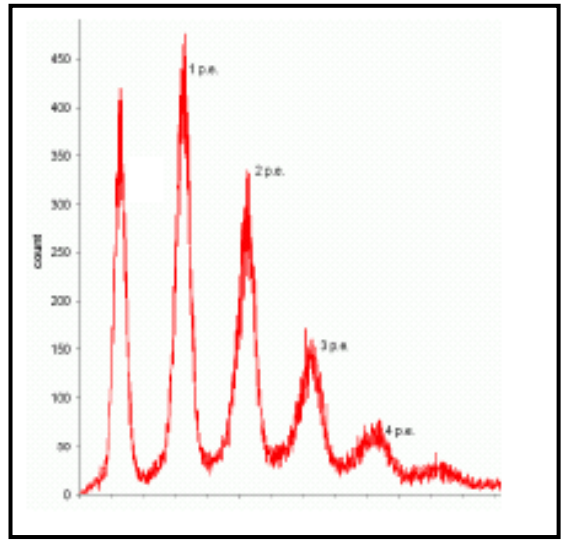
- **Individual fiber readout**
  FGD, POD, Ecal, SMRD, INGRID: ~ 60000 readout channels
- **Limited space for photosensors**
- **Magnetic field**

ND280 photosensor:
Multi-pixel Geiger mode avalanche photodiode
MPPC (Hamamatsu, Japan)

Number of pixels	667
Active area	1.3×1.3 mm
Pixel size	50×50 μm
Gain	0.5×106
PDE at 525 nm	30-35%
Dark rate, th = 0.5 p.e.,22C	<1 MHz
Pulse width	<100 ns
Cross-talk	10-20%
After pulses	10-20%

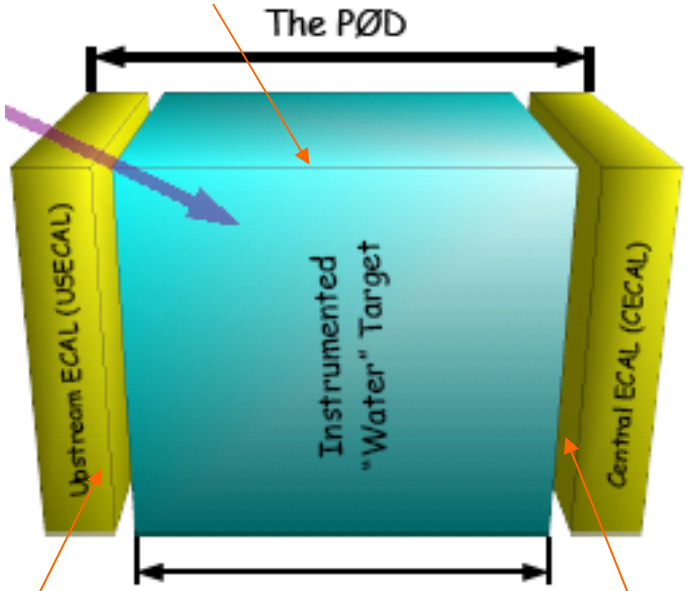






Production on schedule:
Feb08: start mass production
May08: >20000 devices delivered

Fiducial volume

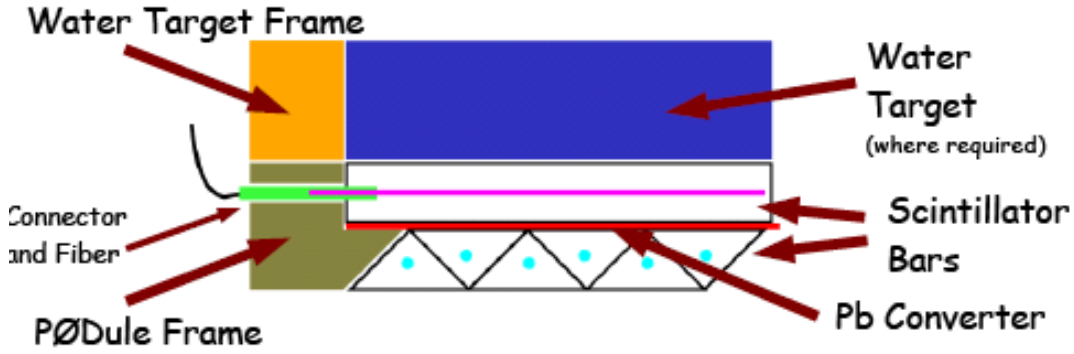


40 layers of X-Y scintillator
25 water layers

Target	**11.0 t**
Water	**2.8 t**
Total mass	**17.6 t**

Expected efficiency of π^0 reconstruction ~33%

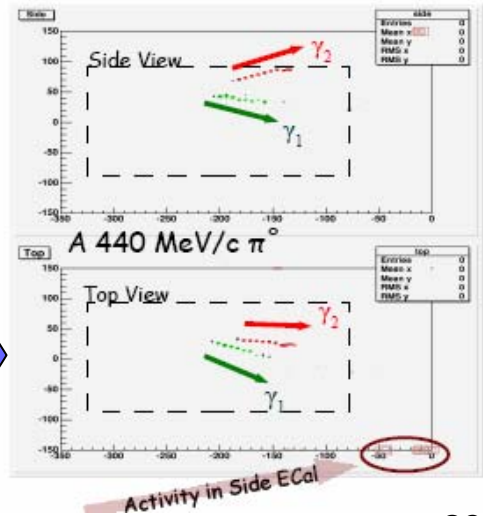
POD



Differences Between Target and ECal PØDules

- Target PØDules
  - 0.6 mm Lead to convert γs
  - 26 PØDules
- ECal PØDules
  - Pb is ~2 mm (x2) to contain showers
  - 14 PØDules

Typical simulated π^0 events

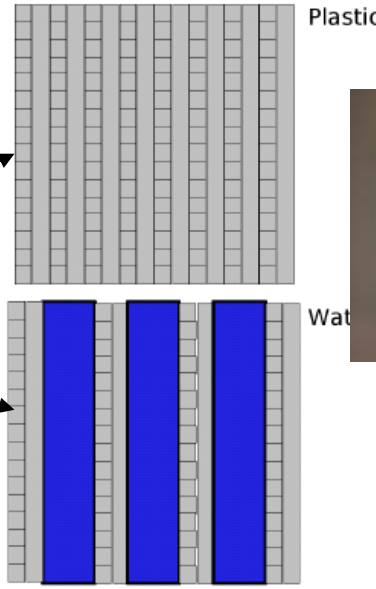


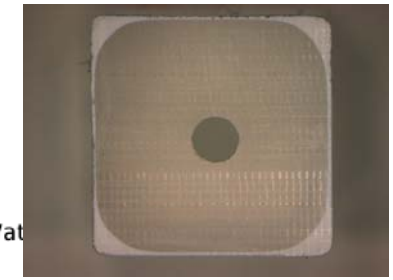
FGD

Two FGD's

1st: x-y layers of scintillators

2nd: water rich detector

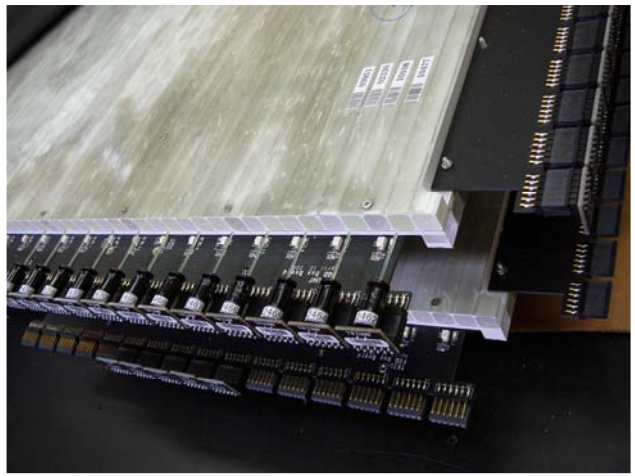




scintillator bar

Size of FGD ~ 2.3 m x 2.4 m x 36 cm
with 1cm x 1cm scintillator bars
Total weight 1.2 ton / FGD
Thickness 0.36 m
to make particles get out of FGD into TPC

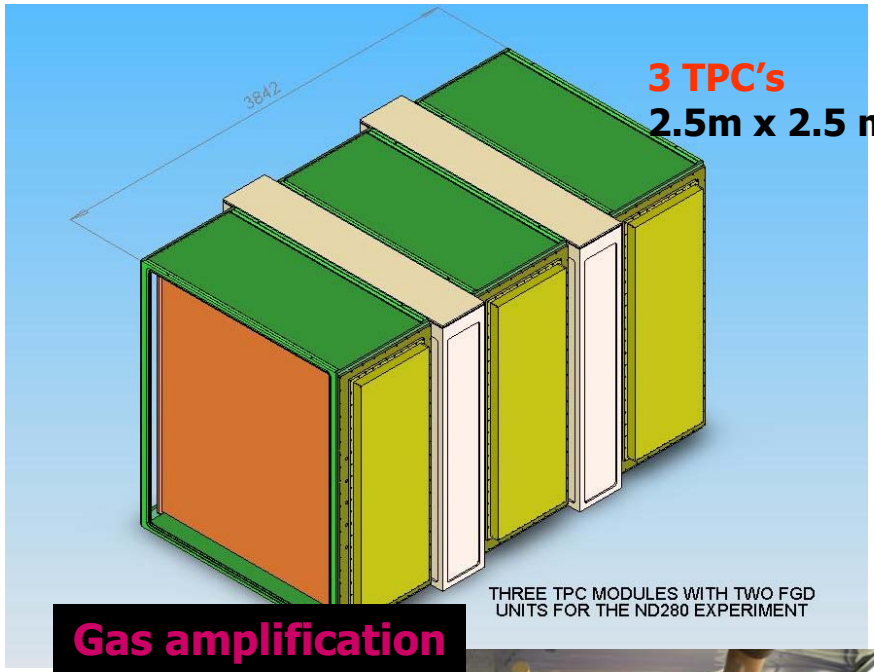
All FGD layers are manufactured, assembly in progress



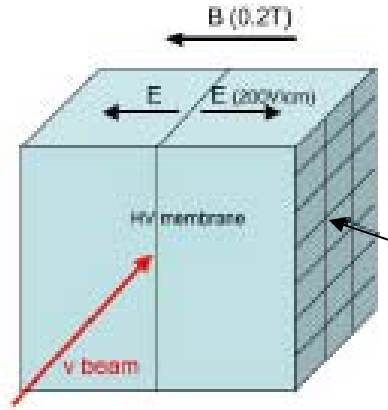
TPC

gas time projection chamber modules (TPC)

Requirements :
σ(p)/p < 10 % at 1 GeV/c
dE/dx capability: separate e from μ

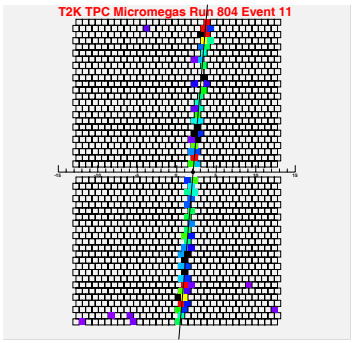


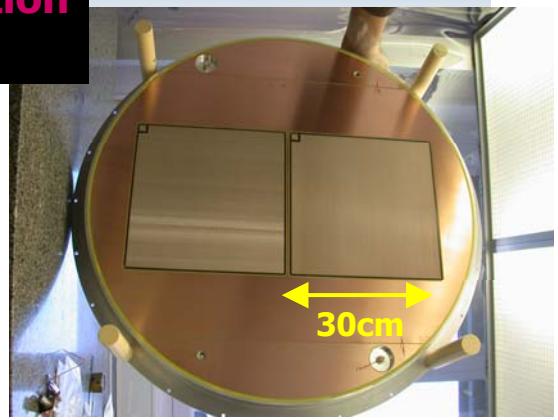
3 TPC's
2.5m x 2.5 m x 90 cm



30x30 cm^2 readout

Gas amplification Micromegas

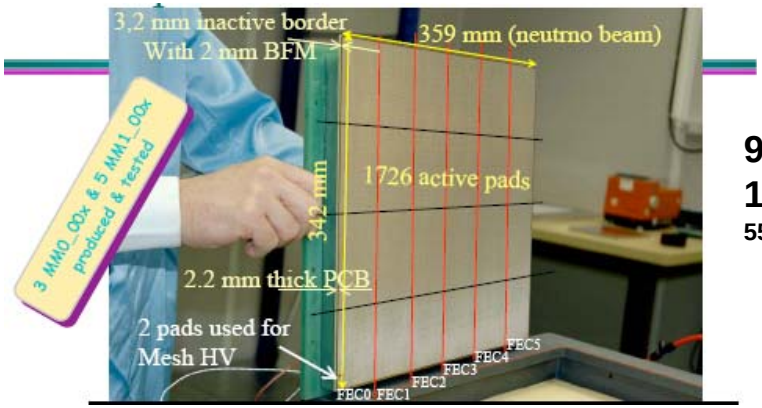




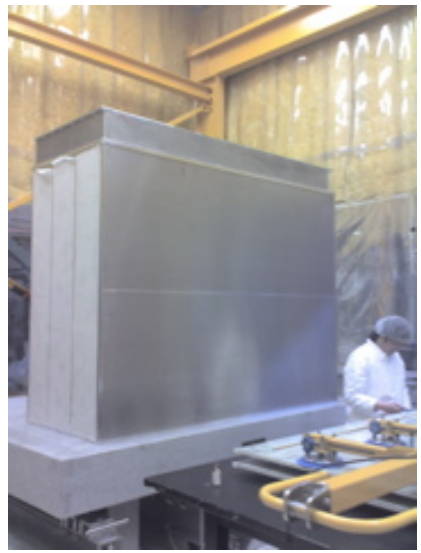
- **6 read-out planes (0.7x2.0 m^2)**
- **Maximum drift distance 1.0 m**
- **B=0.2 T E=200V/cm**
- **Pad size: 8x8 mm^2**
- **100000 channels**

TPC

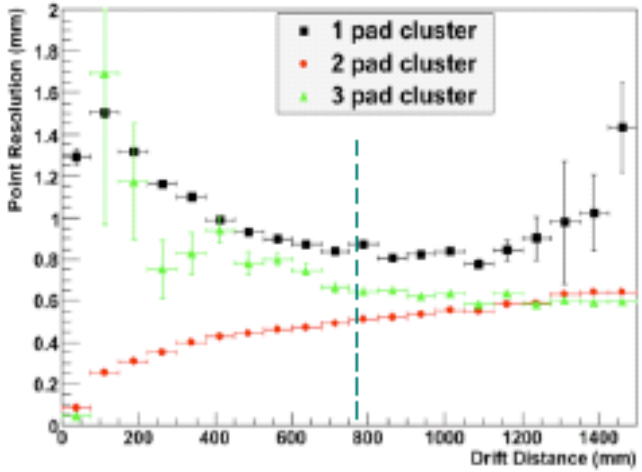
Prototype: MM1_001

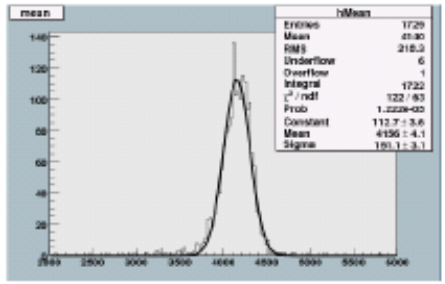


95% Ar + 2% iC4H10 + 3%CF4
128 μm gap, gain 1000
^{55}Fe 5.9 keV FWHM = 19%

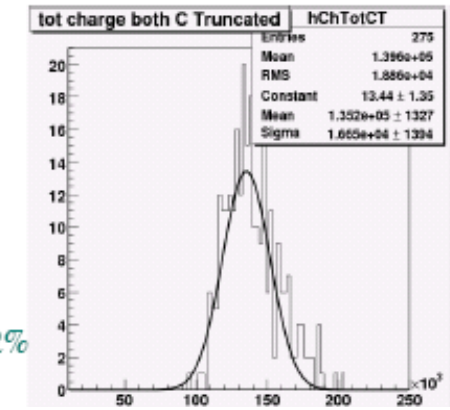


Cosmic test of final prototype at HARP Field Cage



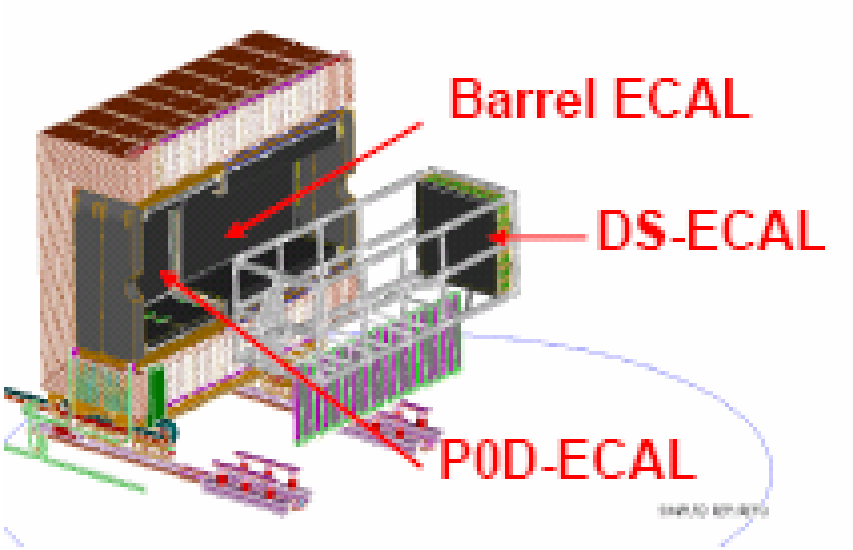


σ of pad gain = 3.4%



dE/dx resolution = 12.2%

ECAL



$10X_0$ Ecal around central detectors
- π^0, γ detection
- Charged PID (e,π,μ)
-Veto incoming particles

Sandwich: 1.75 mm (Pb)/1 cm scint
WLS fiber readout

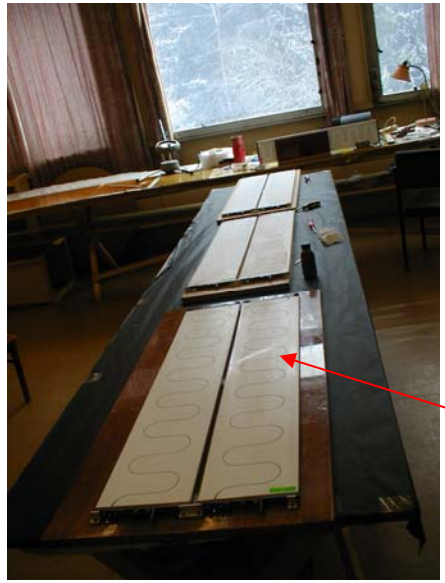
Scintillator bar

2x2 m^2 DS Ecal

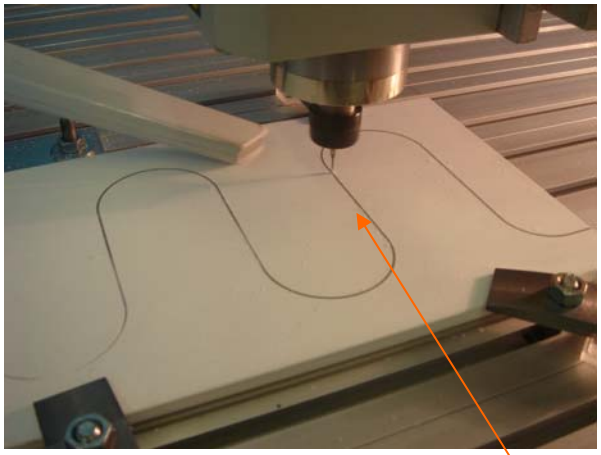
First production layer, March 2008

28 layers, May 2008

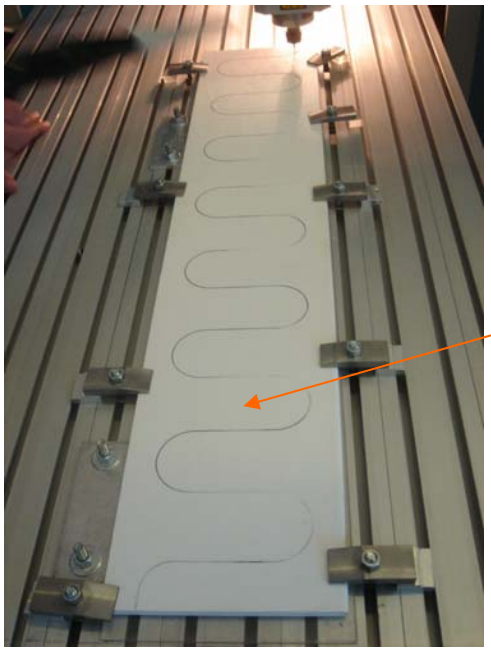
SMRD detectors



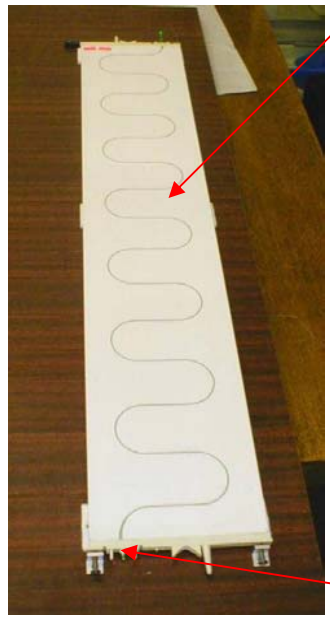
Completion March 2009:
Installation Summer 2009



Y11 fibers embedded and glued



Preparation of S-grooves



Wrapping into stainless steel foil

MPPC

ND280 status

- UA1/NOMAD magnet is refurbished and shipped to JPARC
  - assembly and installation in progress
- All ND280 subdetectors are in production
  (except for barrel ECAL)
- Installation in ND280 pit will start in early 2009
  - On-axis neutrino monitor will be completed by April 2009, to be ready for ν beam
  - Off-axis detector will be completed by fall 2009 to start data taking in the end of 2009

Plan & Conclusion

T2K is expected to provide very exiting physics

primary goal: discovery of $\nu_\mu \rightarrow \nu_e$

Main features: off-axis intensive ν_μ **beam from JPARC, SuperK and ND280m Complex**

J-PARC accelerator complex is being commissioned

Neutrino beam **April 2009**

key system for beam commissioning
INGRID will be ready to detect neutrinos

ND280m (off-axis) **Summer 2009**

installation in UA1/NOMAD magnet

Physics run **Fall 2009**

ND280 starts data taking
for oscillation and non-oscillation physics

First T2K result **Summer 2010**