Status of the long baseline neutrino experiment T2K

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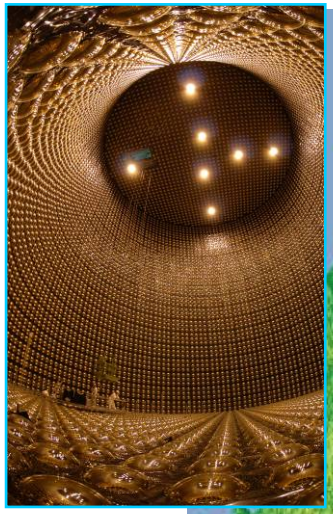
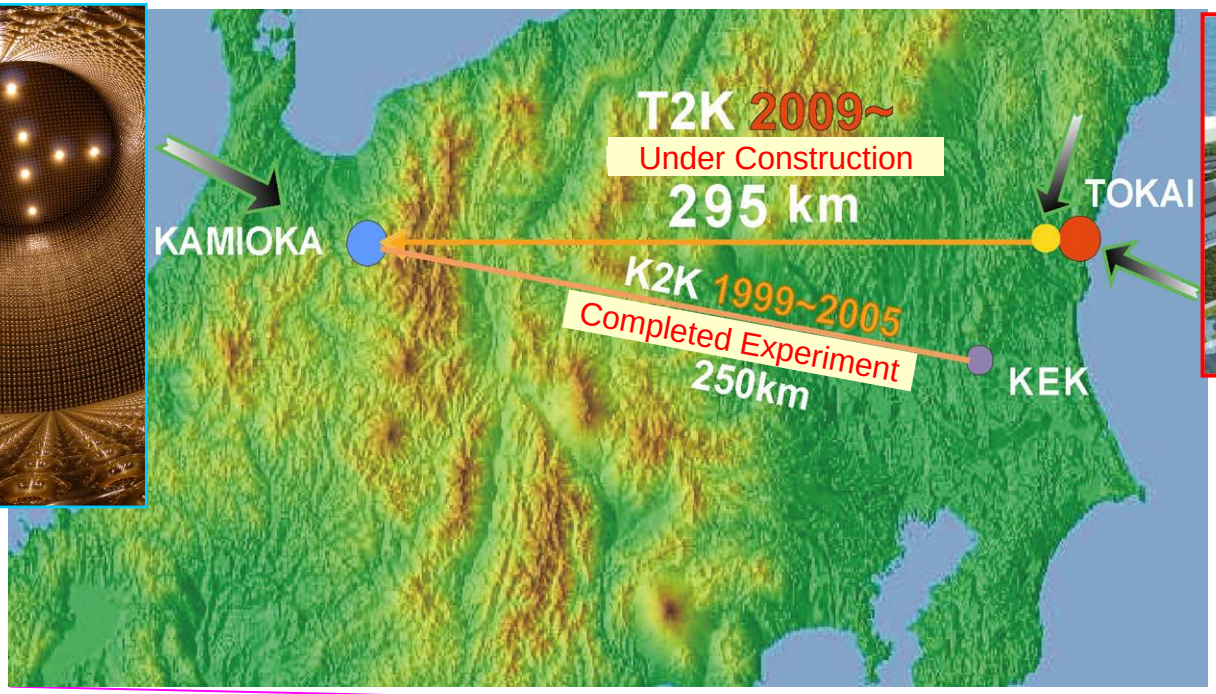
(For the T2K Collaboration)

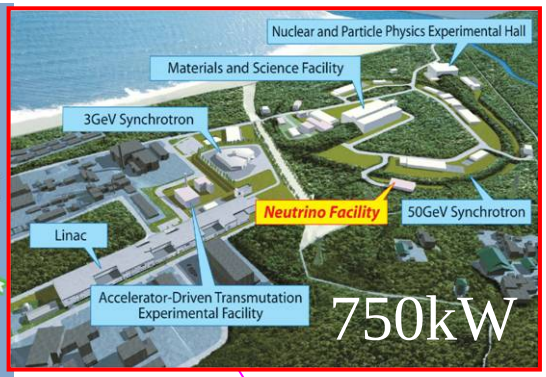
Institute for Nuclear Research
Moscow

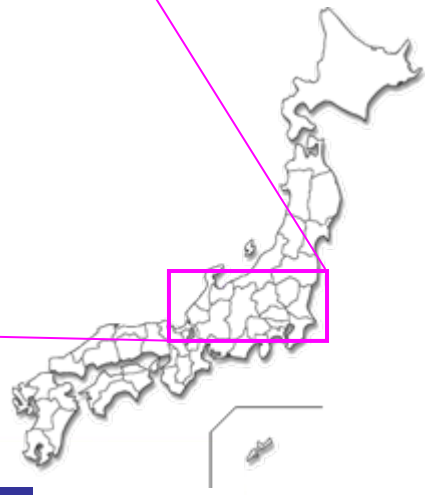
Dubna, 28 January 2009

T2K (Tokai to Kamioka) LBL neutrino experiment

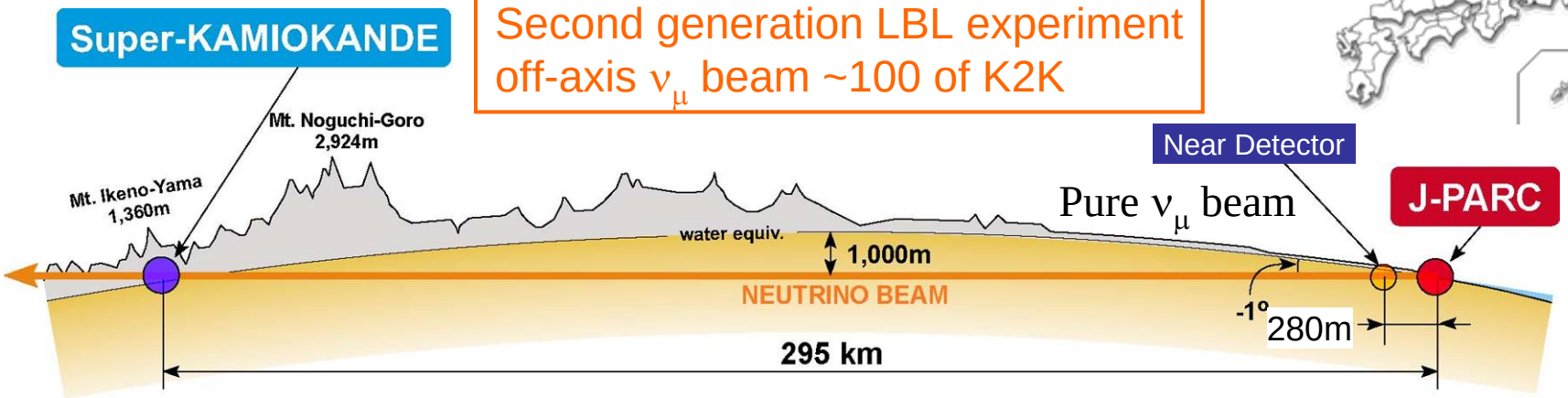








Second generation LBL experiment
off-axis ν_μ beam ~100 of K2K



The T2K Collaboration

407 members, 65 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
U. Hiroshima
ICRR
ICRR Kamioka
ICRR RCCN
KEK
Kyoto U.
U. Kobe
U. Miyagi
U. Osaka City
U. Tokyo

Poland
A. Soltan, Warsaw
IFJ PAN, Krakow
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroklaw

Russia
INR

S. Korea
N. U. Chonnam
U. Dongshin
N. U. Gyeongsang
N. U. Kyungpook
U. Sejong
N. U. Seoul
U. Sungkyunkwa

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

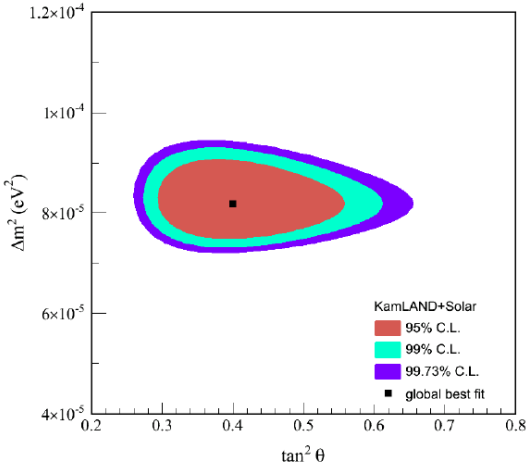
USA
Boston U.
B.N.L.
Colorado S. U.
Duke U.
Louisiana S. U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

Neutrino mass and mixings

3 mixing angles (θ_{12}, θ_{23}, θ_{13})
1 CPV phase (δ)
2 (independent) mass differences ($\Delta m^2_{ij}=m_i^2-m_j^2$)

θ_{12}, Δm_{12}^2

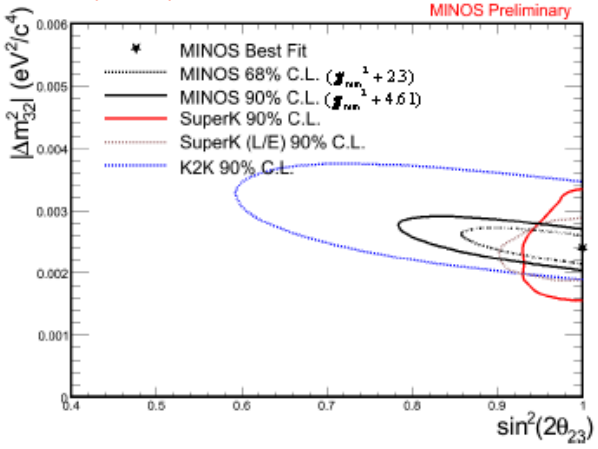
$\Delta m^2_{solar} = 8 \times 10^{-5}$ eV^2
$\sin^2(2\theta_{12}) = 0.86$



Solar + KamLAND

θ_{23}, Δm_{32}^2

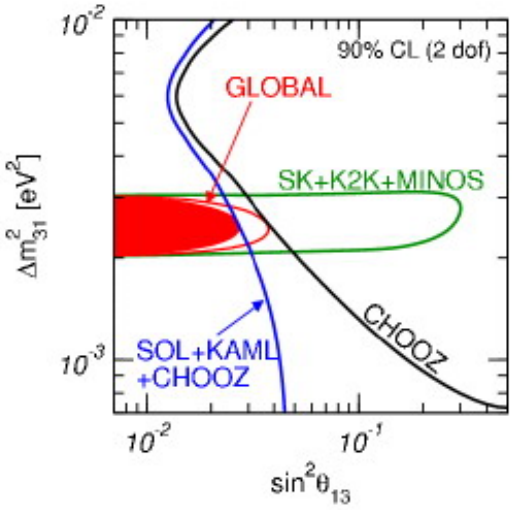
$\Delta m^2_{atm} = (2.2\sim2.6) \times 10^{-3}$ eV^2
$\sin^2(2\theta_{23}) > 0.92$



SK + K2K + MINOS

θ_{13}, Δm_{31}^2

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



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

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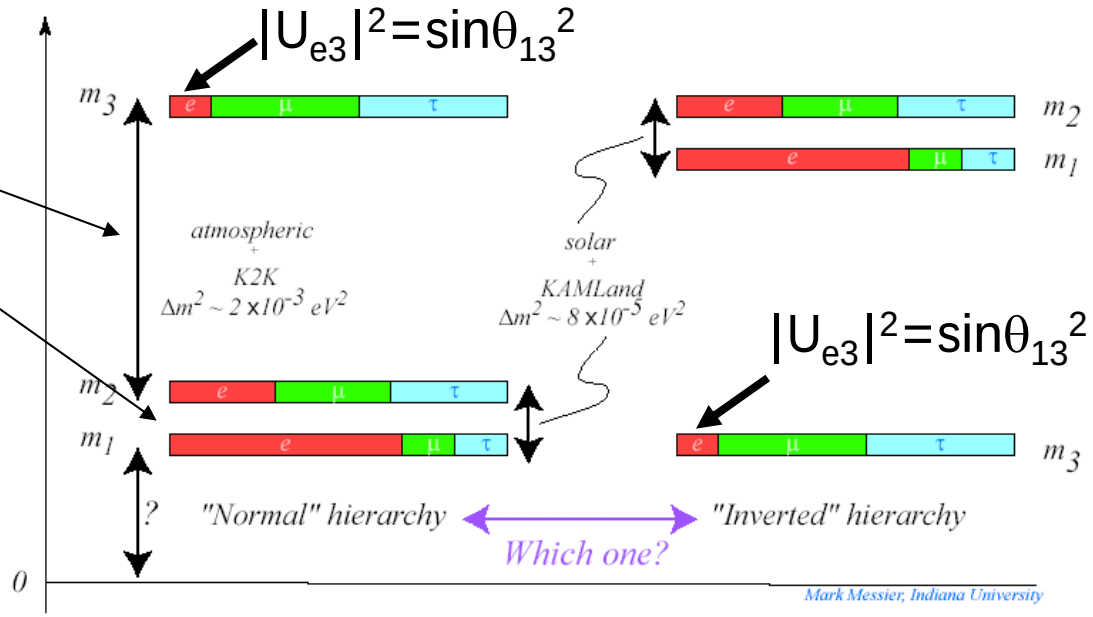
Present knowledge and next steps

$\Delta m^2_{23} \sim 0.0025 eV^2$

$\Delta m^2_{12} \sim 0.00008 eV^2$

Large mixing { $\theta_{12} \sim 33^o$ $\theta_{23} \sim 45^o$

??

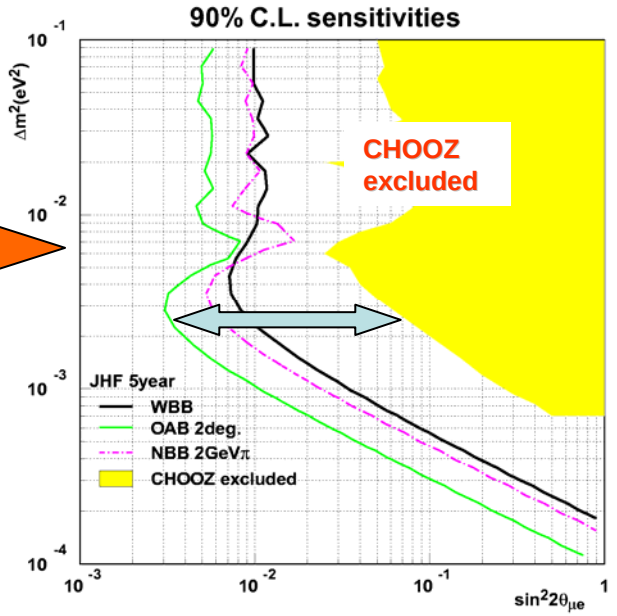


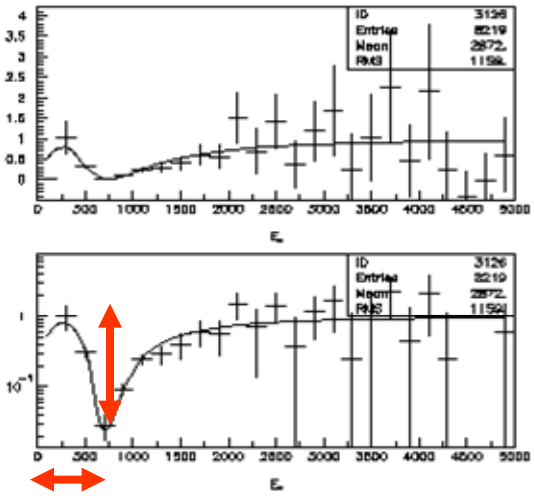
- Mixing angle θ_{13}
- Mass hierarchy (sign of Δm^2_{23} $\rightarrow$ $m_3 > m_1$ or $m_3 < m_1$)
- CP violation
- Absolute mass scale
- Dirac or Majorana
- Approaches
  - LBL experiments: multi purpose (θ_{13}, sign(Δm^2), CPV, θ_{23}, Δm^2_{23})
  - Reactor-based ν_e disappearance: single purpose (θ_{13}), complementary

Goals of T2K

- Search for ν_e appearance
  sensitivity $\sin^2 2\theta_{13} \leq 0.01$

$\nu_\mu \rightarrow \nu_e$





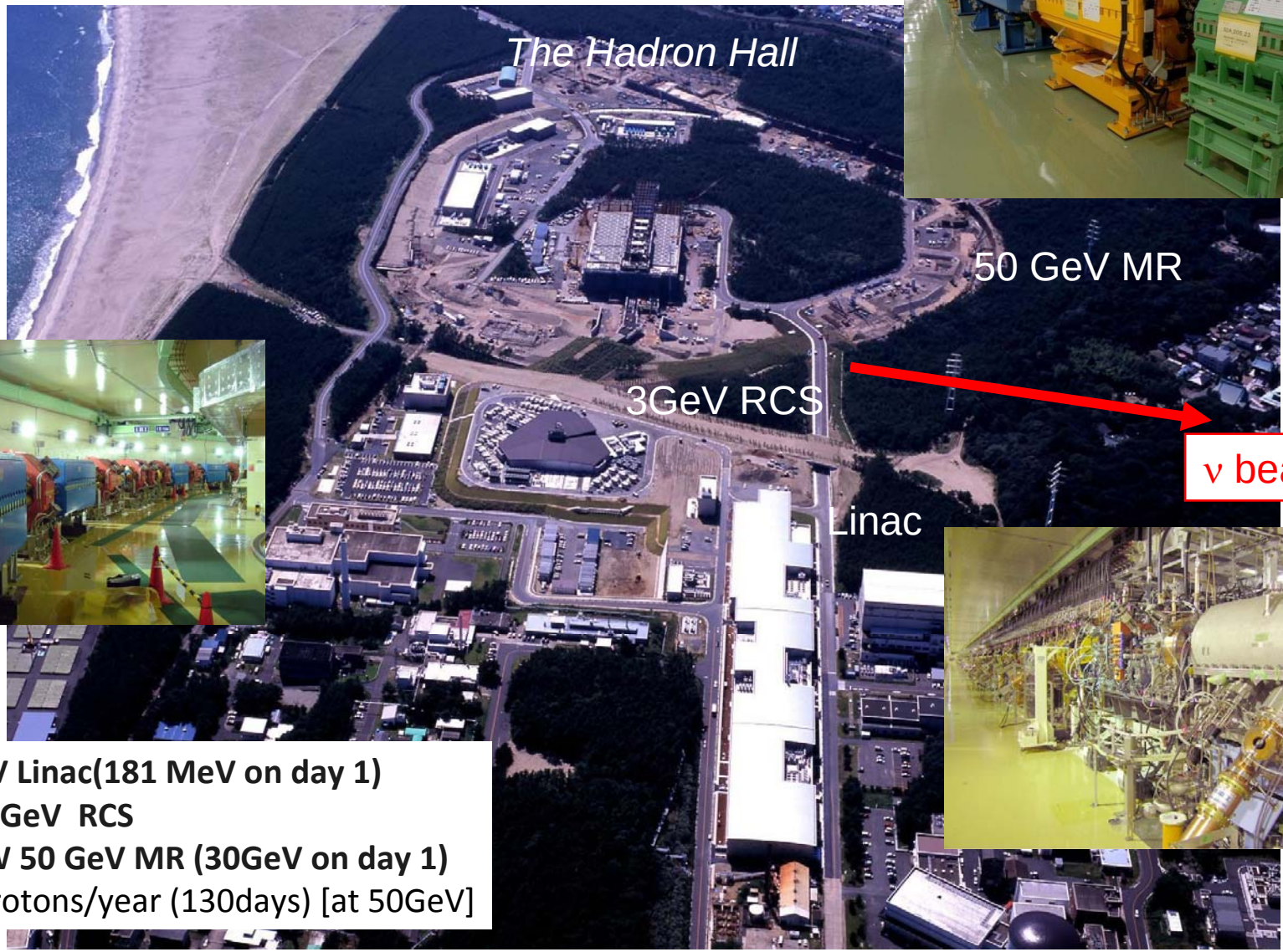
$\nu_\mu \rightarrow \nu_\mu$

- Measurement of Δm^2_{23} with accuracy of 3%
  and mixing angle with accuracy of 1%

$\delta(\sin^2 2\theta_{23}) \sim 0.01$
$\delta(\Delta m^2_{23}) < 1 \times 10^{-4}$ eV²

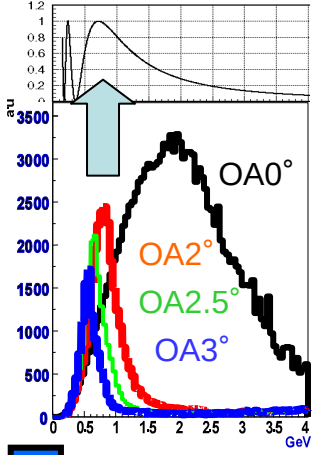
- Confirmation of $\nu_\mu \rightarrow \nu_\tau$ using NC events

JPARC



400 MeV Linac(181 MeV on day 1)
1 MW 3 GeV RCS
0.75 MW 50 GeV MR (30GeV on day 1)
$1x10^{21}$protons/year (130days) [at 50GeV]

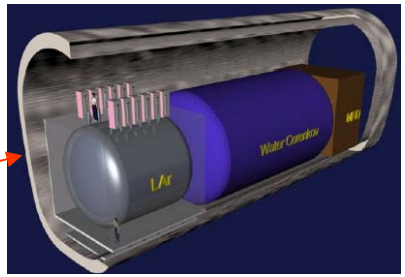
T2K setup



Possible Future

ND280m

ND2km



SK

μ monitor

p

π

off-axis

on-axis

ν

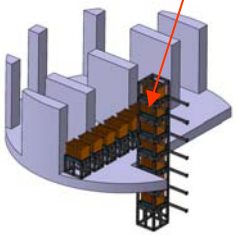
0m

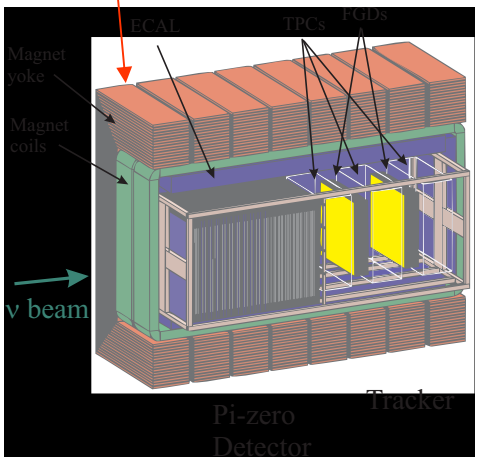
140m

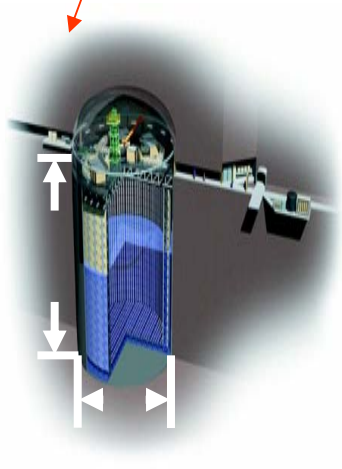
280m

2 km

295 km







Neutrino BeamLine

Target-Horn System

Target Station

Preparation Section

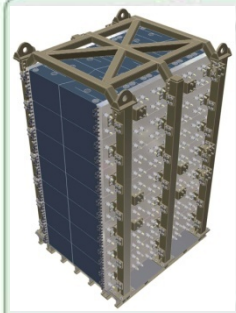
Muon
Monitoring Pit

Final
Focusing
Section

295km to
Super-Kamiokande

100m

Near Neutrino Detector



Beam Dump

Decay Volume

SCFM at ARC Section

Construction: 2004 - 2009 (~ 5 years)

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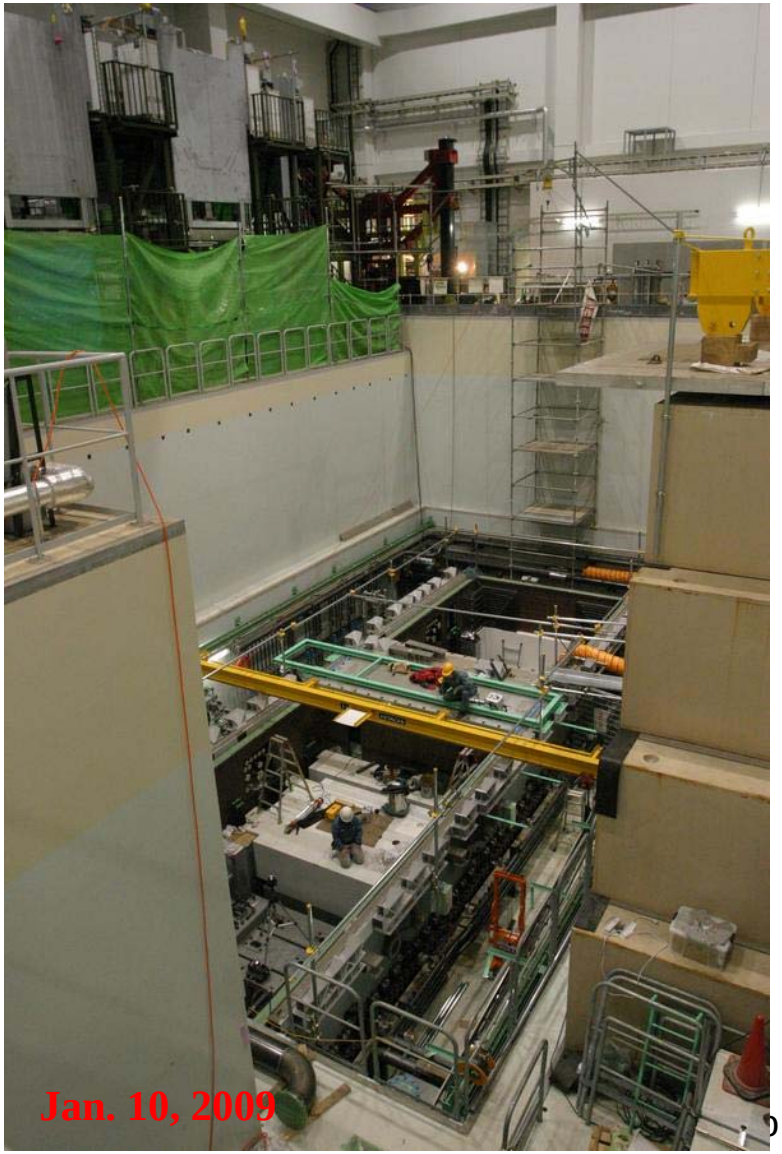
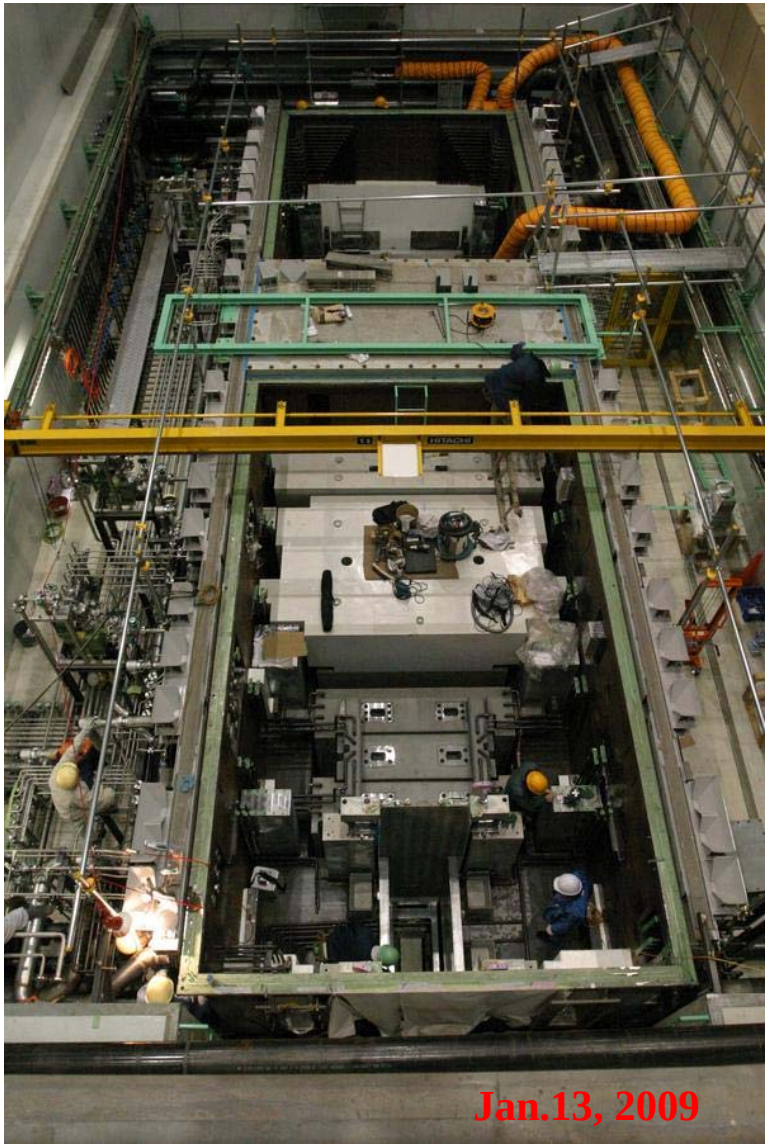
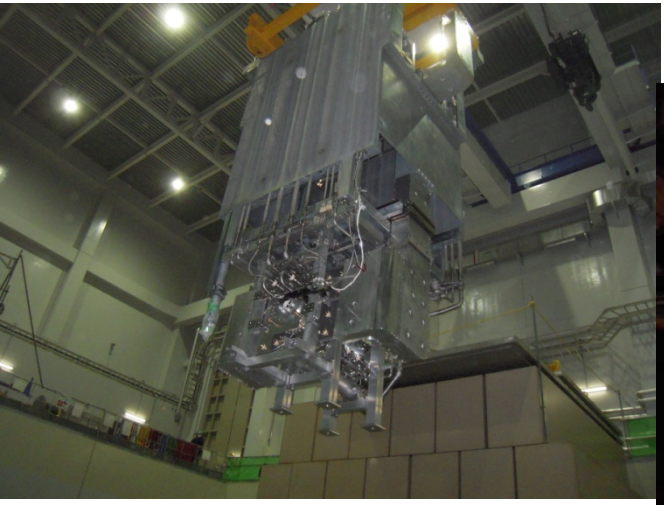
Target Station

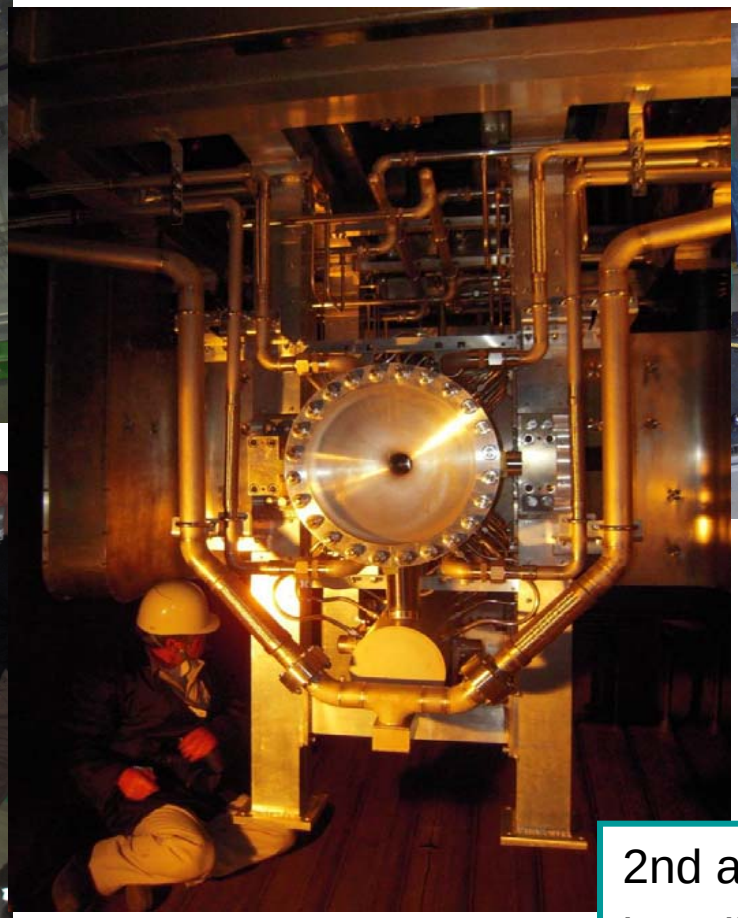




Horn1 Installation

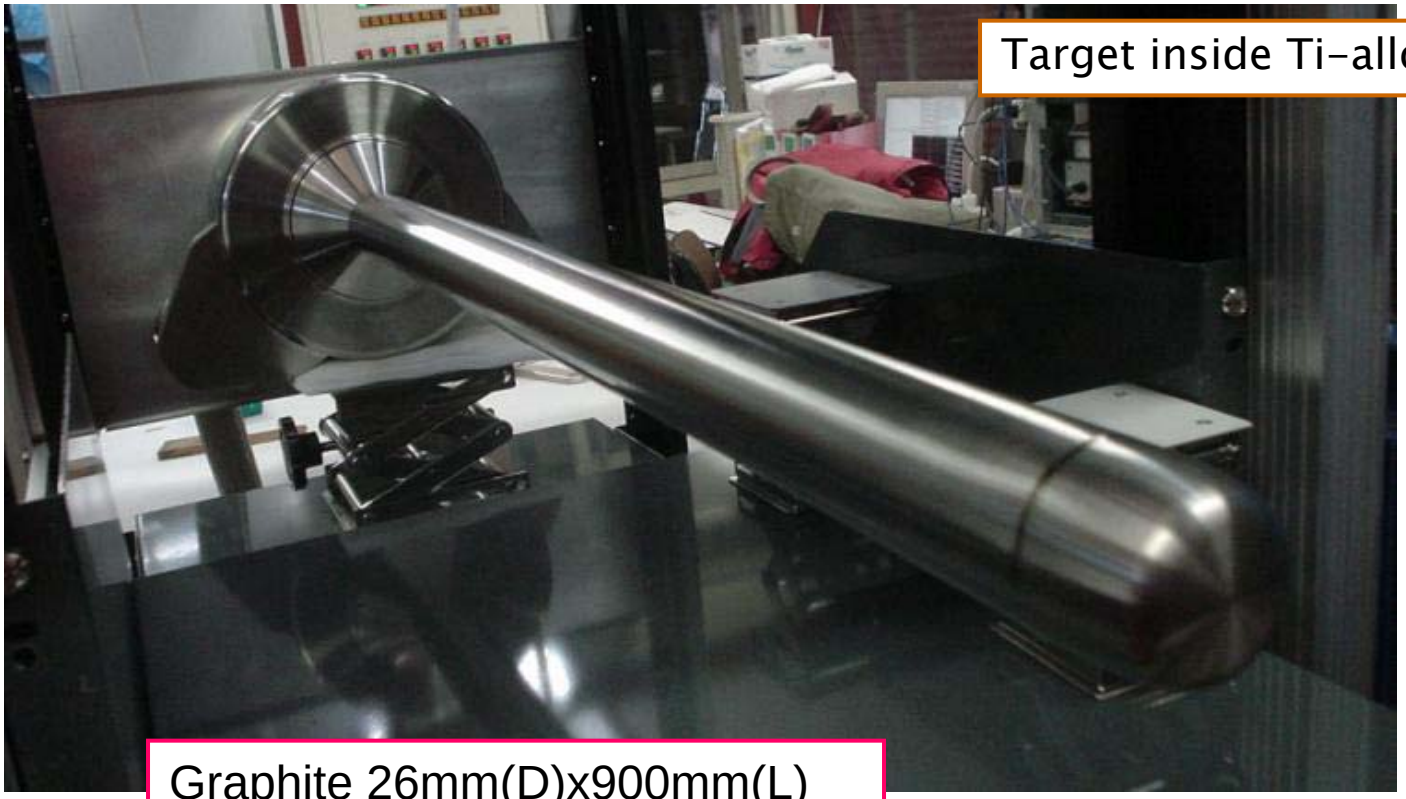
Installation succeeded January 2009





2nd and 3rd horn:
installation in Summer ’09.

T2K Target



Target inside Ti-alloy capsule T2K

Graphite 26mm(D)x900mm(L)
Forced flow Helium gas cooling
in Ti-alloy container
Remotely exchangeable

ND280

Neutrino Facility related with ND280

Pictures taken on Jan.13
(by Yamada-san)

NMU (Neutrino Monitoring Utility building)
• will be available in April

JPARC milestones and timeline

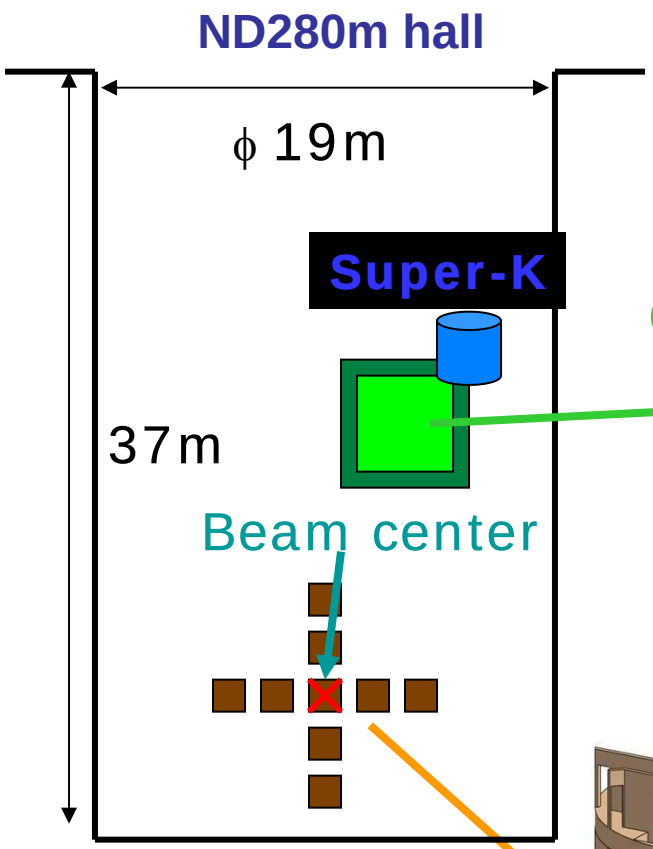
LINAC fully commissioned
181 MeV achieved in January 2007

3 GeV syncrotron (RCS)
3GeV acceleration and extraction in October 2007

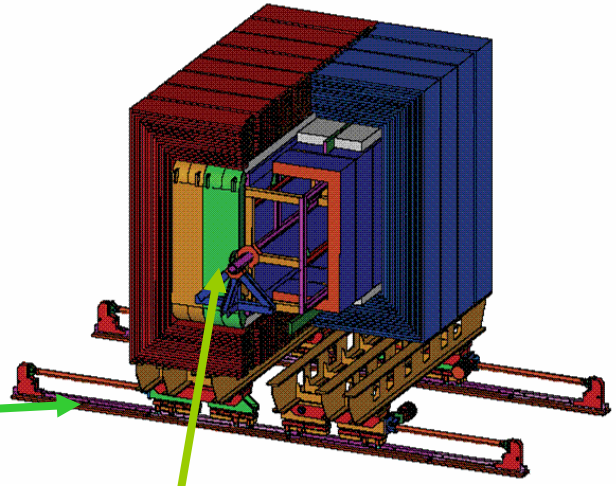
Main Ring
first acceleration of 30 GeV beam December 2008

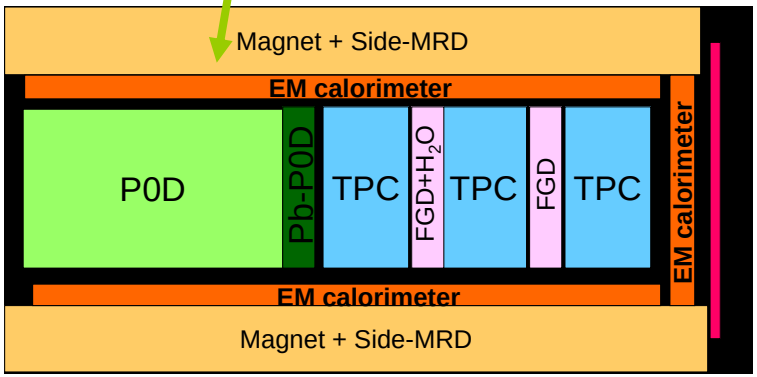
Extration to neutrino beam line April 2009
30 GeV
0.1% Intensity (single bunch)
Bunch width: ~10ns < “Full beam” width (58ns)
Only 1st horn

Near Detectors at 280m

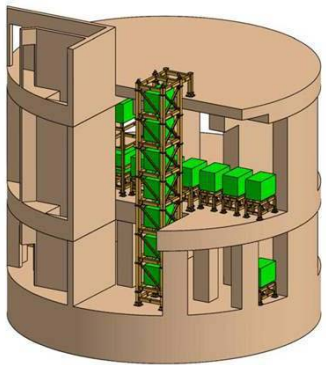


Off-axis (2.5º)

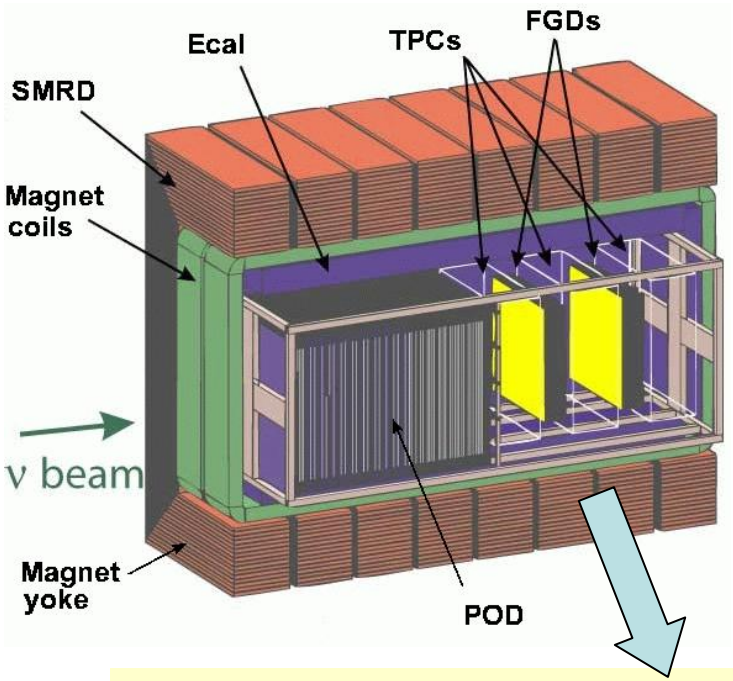


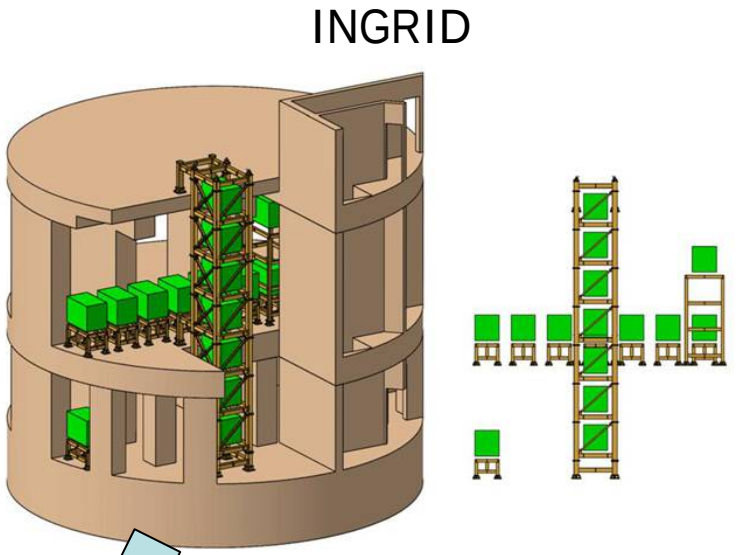


On-axis (0º)
neutrino monitor
INGRID



Photosensor issue





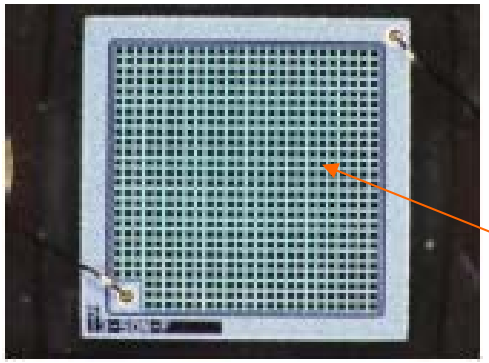
Scintillator detectors with WLS fibers

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

T2K decision in 2004: ND280m baseline photosensor - Multi-pixel Geiger mode avalanche photodiode

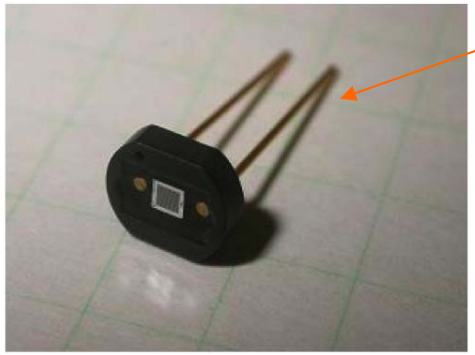
T2K photosensor

R&D for 3 years with 2 options: MRS APD (CPTA, Moscow)
MPPC (Hamamatsu, Japan)



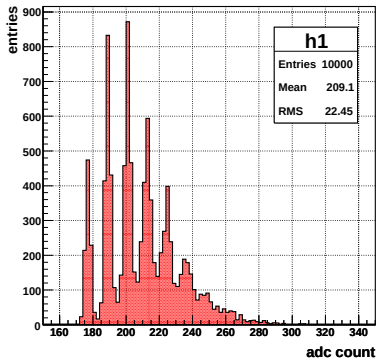
T2K photosensor: MPPC

Hamamatsu MPPC: active area 1.3×1.3 mm^2



Number of pixels	667
Pixel size	50×50 μm
Gain	0.5×10^6
PDE at 525 nm	30-35%
Dark rate, th = 0.5 p.e.,22C	<500 kHz
Pulse width	<100 ns
Cross-talk	10-20%
After pulses	10-20%

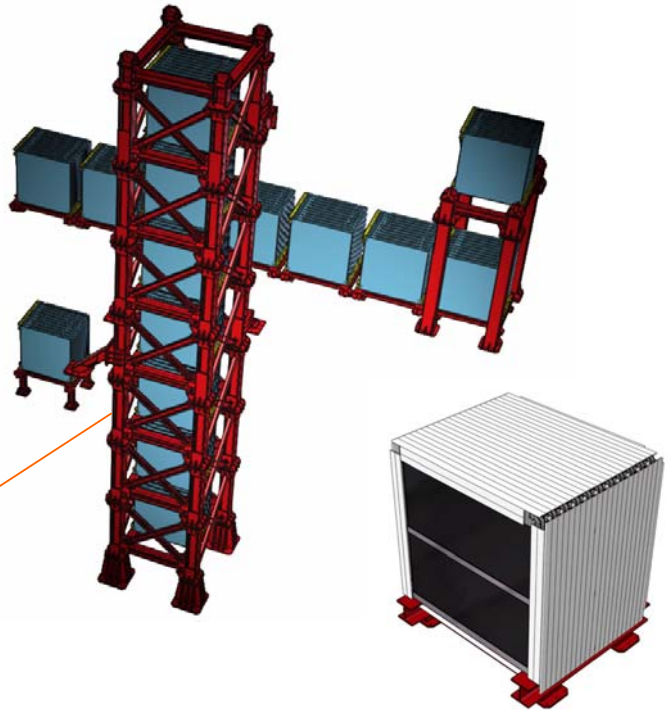
HPK311-53-1A-002-1

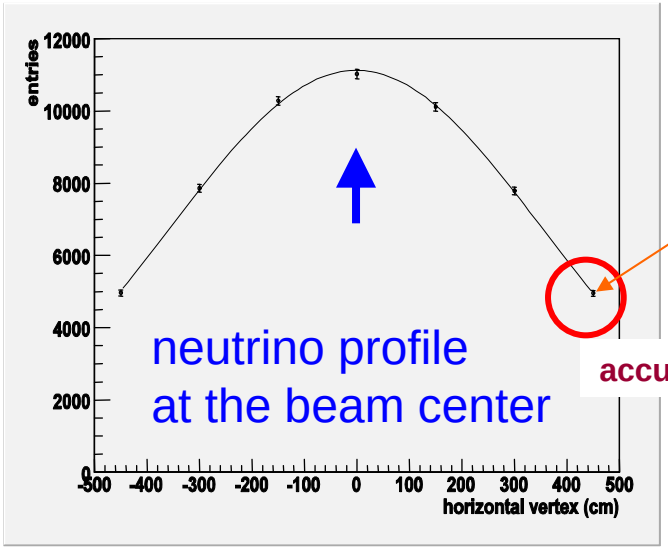


Mass production 60 k devices
started Feb 2008
to be completed Feb 2009

On-Axis Neutrino Monitor (INGRID)

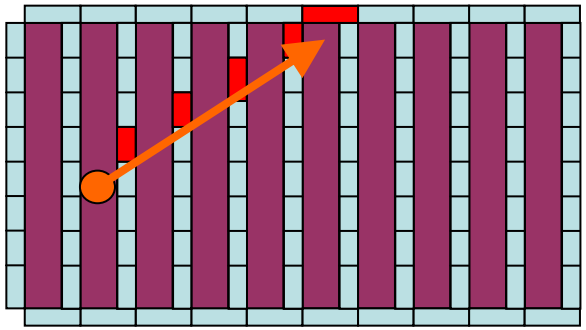
- **Monitor the neutrino beam**
  - **Direction**
  - **Profile**
  - **Intensity (& Energy)**
- **Iron-Scintillator sandwich detector:** **16 modules**
- **Each module consists of**
  - **10 Iron layers**
  - **11 layers of extruded scintillator strips 1x5x100 cm³**
  - **4 side veto planes**
  - **WLS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





Event Rate/module

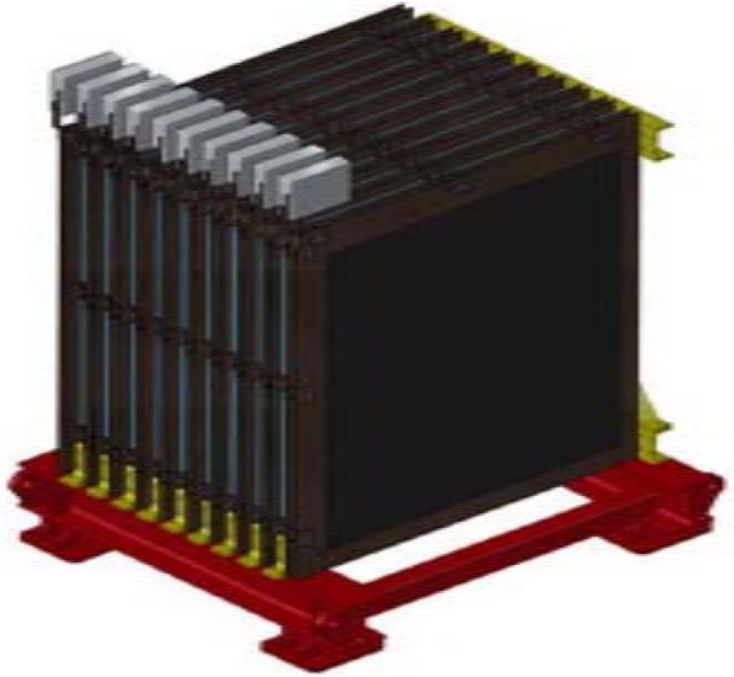
accuracy ~ 0.18 mrad



INGRID

• The first INGRID module will be installed in **March 2009** and ready for beam in April
• 15 modules will be installed by **Summer 2009**

•228 scintillator planes are built
•9592 channels are tested.



ND280m off-axis detector

Refurbished UA1/NOMAD magnet

0.2 T

inner volume: 3.5×3.6×7.0 m^3

Pi-Zero (POD)

Optimized for π^0 from NC

Measure ν_e contamination

Tracker (2FGD + 3 TPC)

Optimized for CC studies

Measure ν beam flux, E spectrum, charged particle momenta, particle ID

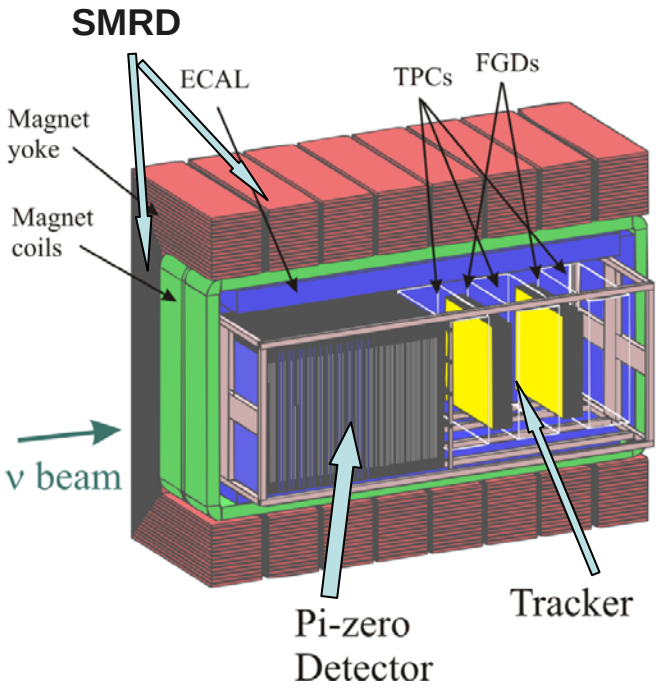
ECAL

Photon detection from π^0 in POD and tracker

Side Muon Range Detector

Measure momentum for lateral muons

Provide trigger on cosmic rays

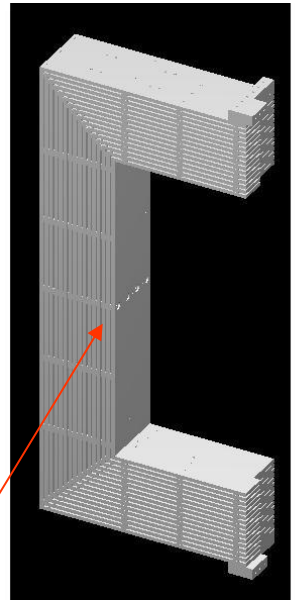


UA1/NOMAD magnet

Total weight about 1 kt
Field 0.2T

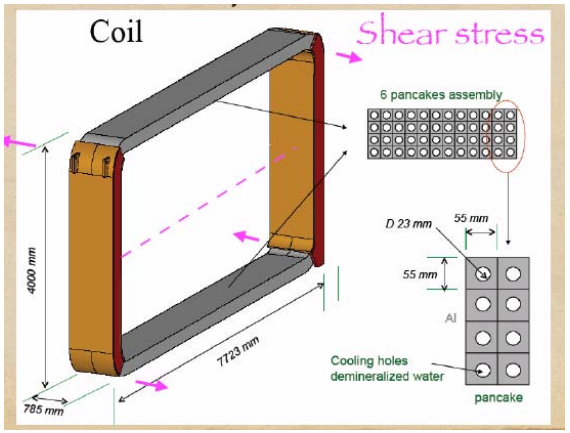
Being shipped from CERN to Japan
Installed in ND280 pit in 2008

16 C-shape yokes



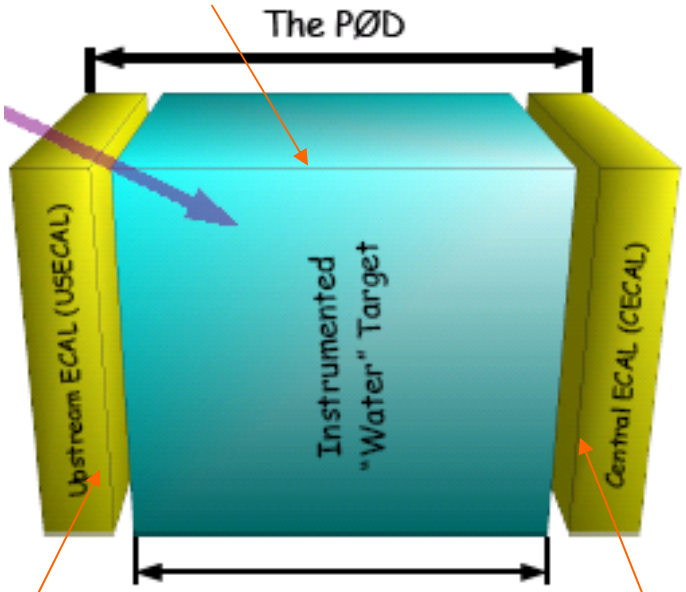
Instrumented with scintillators

4 coils

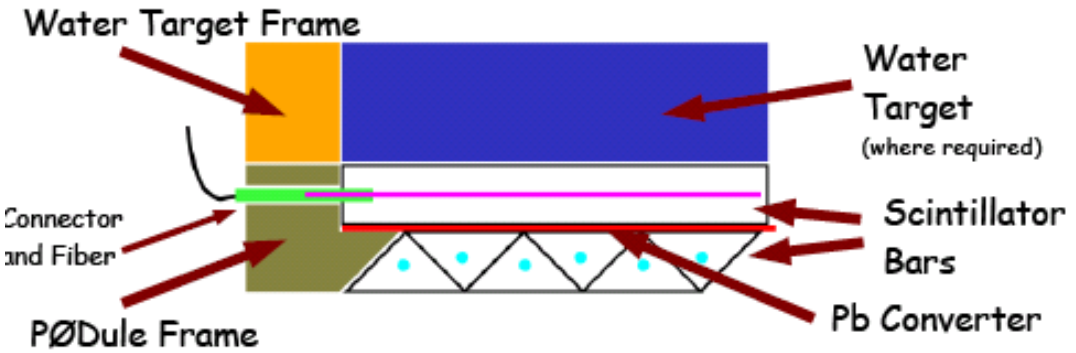


POD

Fiducial volume



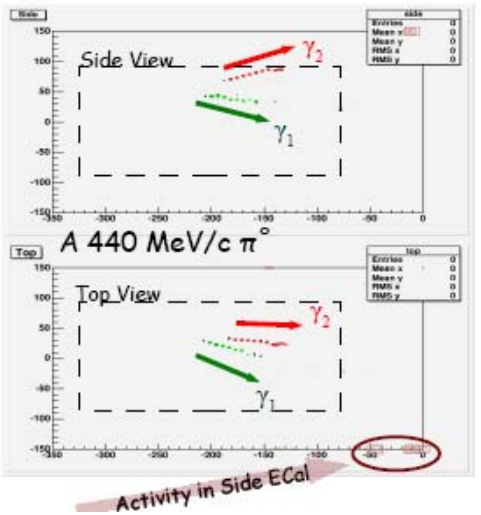
- 3 Super-PØDules
  - Upstream ECAL (3200 kg)
    - 7 PØDules
    - 7 4mm-thick lead radiators
  - Target (11000 kg)
    - 2857.3 kg water
    - 26 PØDules
    - 25 1.6mm brass radiators
    - 25 Water target layers
    - Split into 2 sub-units for pre-installation handling
  - Central ECAL (3200 kg)
    - 7 PØDules
    - 7 4mm-thick lead radiators
- Total Mass is 17600 kg



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

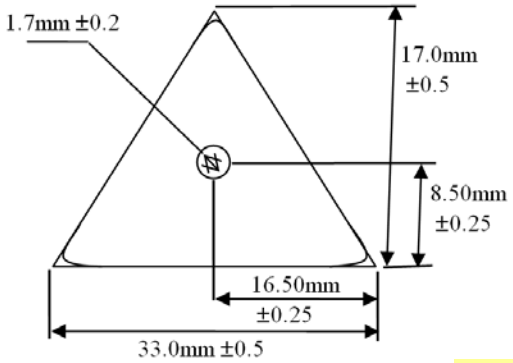
Typical simulated π^0 events



Expected efficiency of π^0 reconstruction ~33%

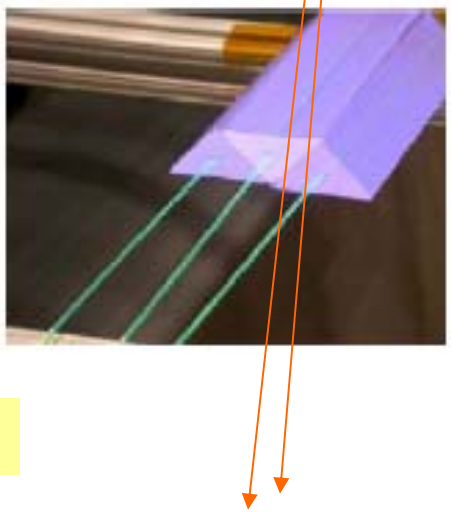
POD scintillator test

Requirement driven by shower reconstruction efficiency
L.Y. > 5 p.e./MeV at far end



Active material length ~ 16mm
on vertical for two bars

cosmic ray muons



Readout:1.3x1.3 mm^2 667 pixel MPPC

Without mirror

Position (cm)	Yield (p.e.)	p.e./cm	p.e./MeV
25 cm	67.3 +- 0.9	39.6 +- 0.6	19.8 +- 0.3
205 cm	29.7 +- 0.8	17.5 +- 0.3	8.7 +- 0.2

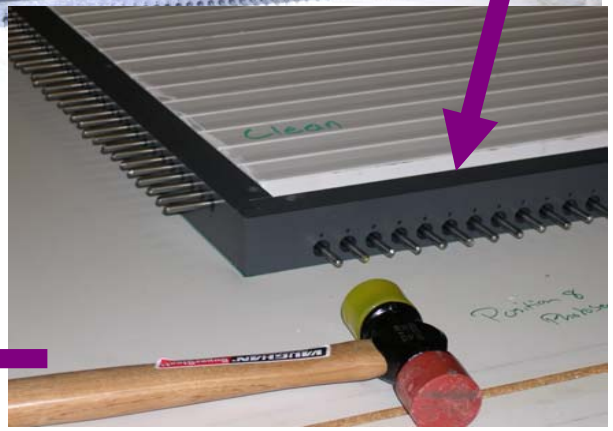
With mirror (expect): 23.8 p.e./MeV (25 cm) 15.7p.e./MeV (205 cm)

PØDule

Assembly Table

Dry Assembly

Gluing



Glued PØDule
next step, insert fibers

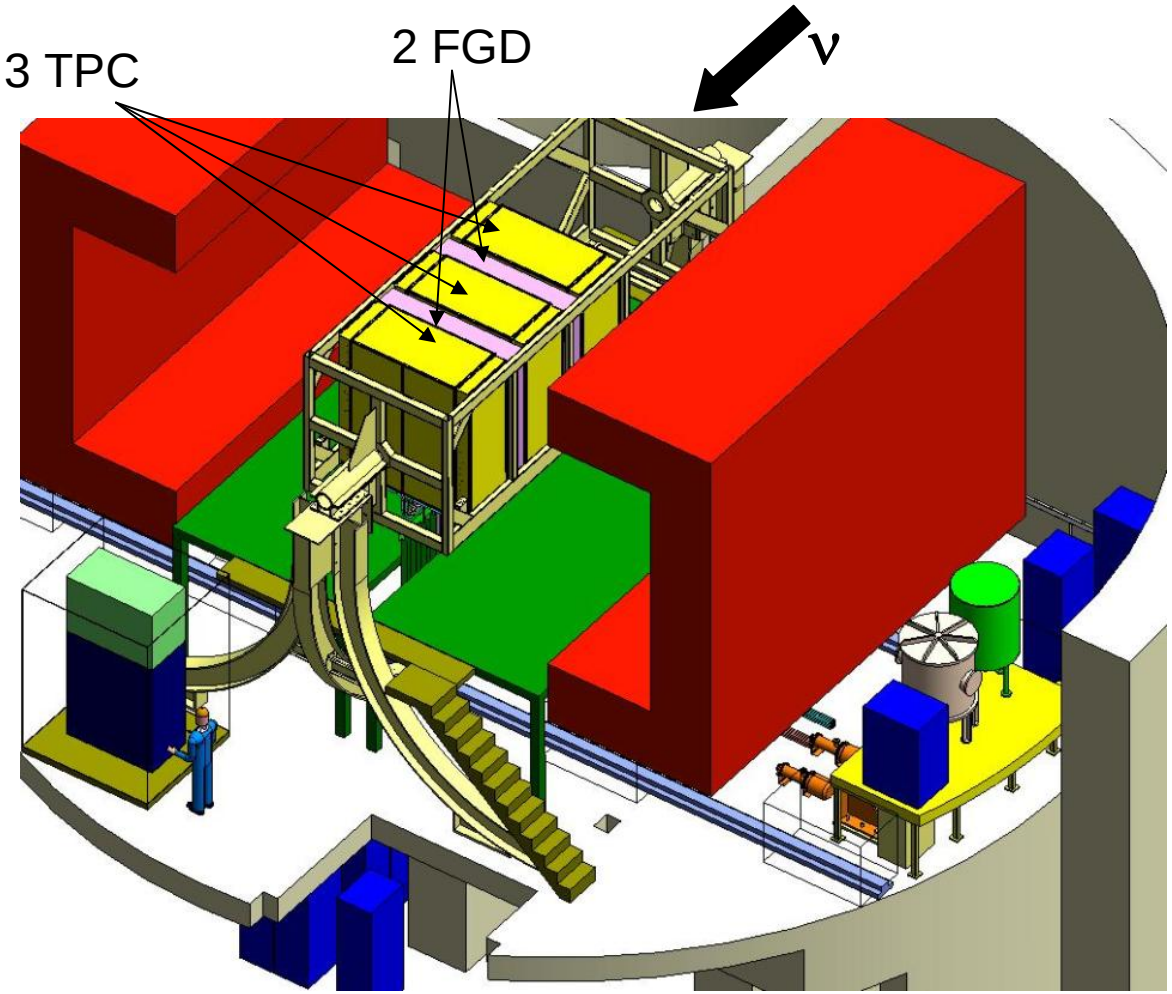
POD

Lead

Completed Ecal S-P0D with 7 P0Dules and 7 lead radiators

Tracker: mechanical design

The tracker is supported by a basket within the UA1 magnet



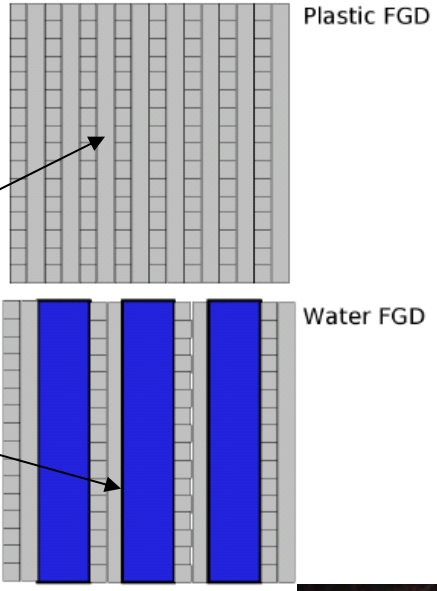
FGD

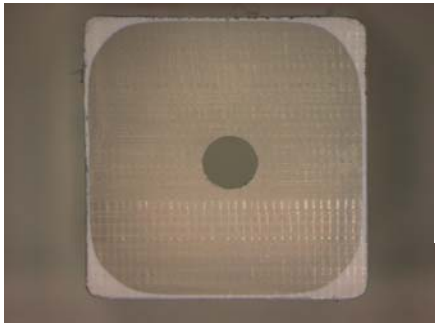
Two FGD's

1st: x-y layers of scintillators

2nd: water rich detector

6 x 2.5cm water target panels

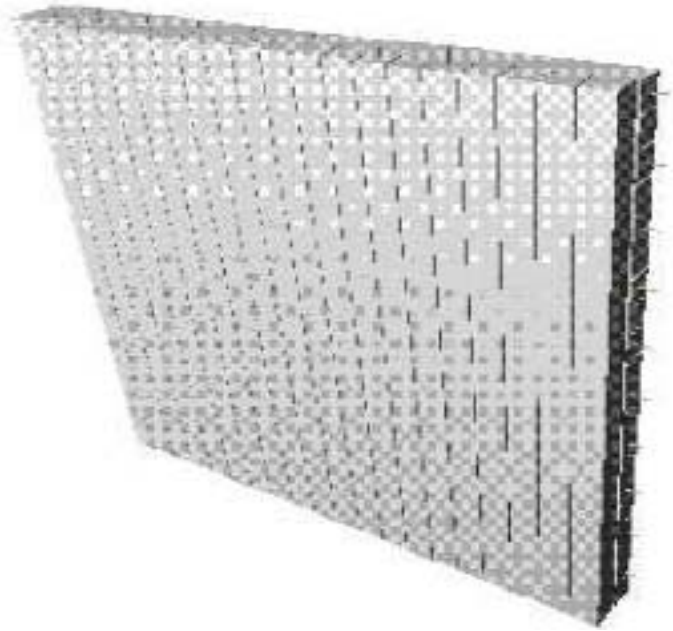


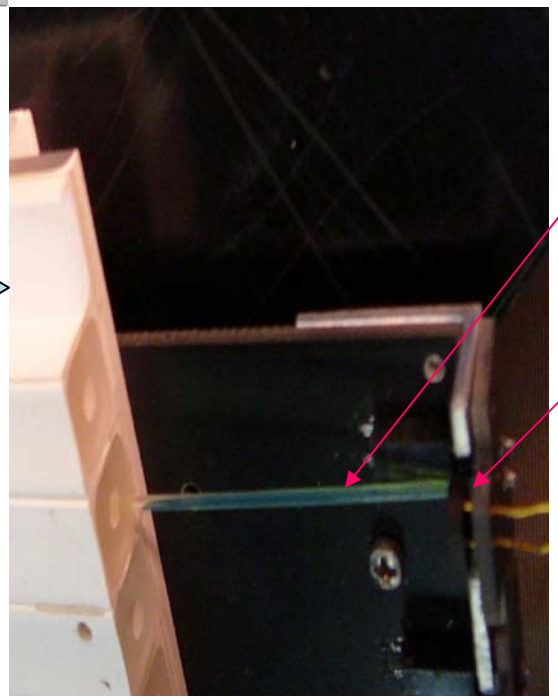


9.6mm x 9.6mm polystyrene scintillator bar with WLS fiber readout

Full FGD has ~5800 channels

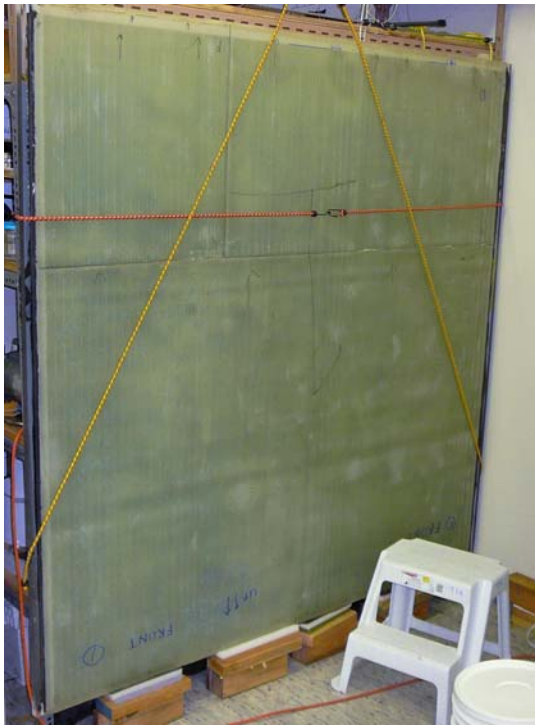
1.2 tonnes active mass





FGD

- Plastic FGD: 15 XY modules (30 layers thick).
- Water FGD: 7 XY modules alternate with 6 water layers (2.5cm thick)



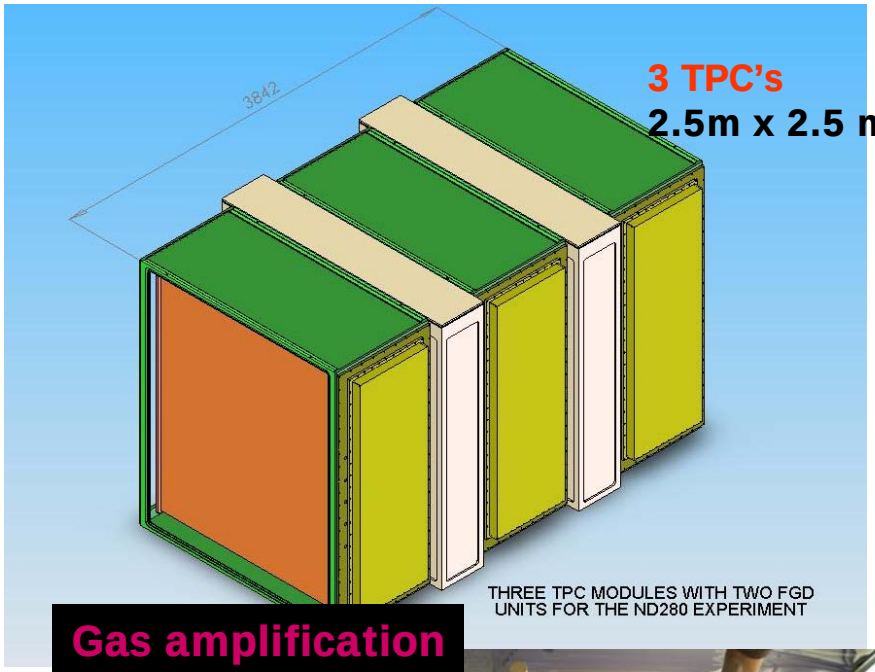
completed water module

x-y plane

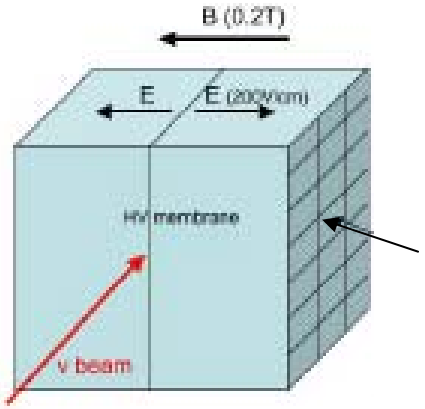
TPC

gas time projection chamber modules (TPC)

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

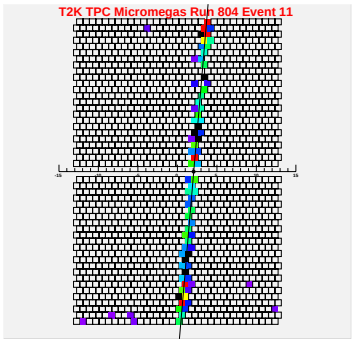


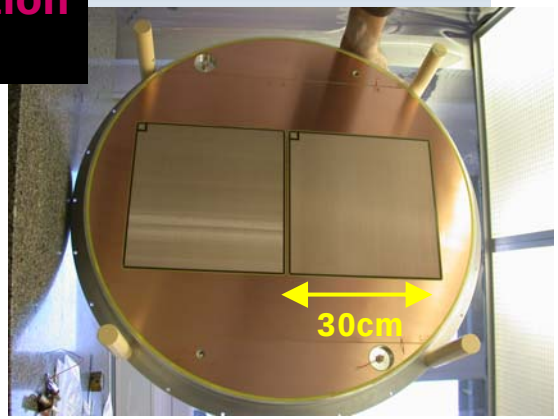
3 TPC's
2.5m x 2.5 m x 90 cm



30x30 cm^2 readout

Gas amplification Micromegas



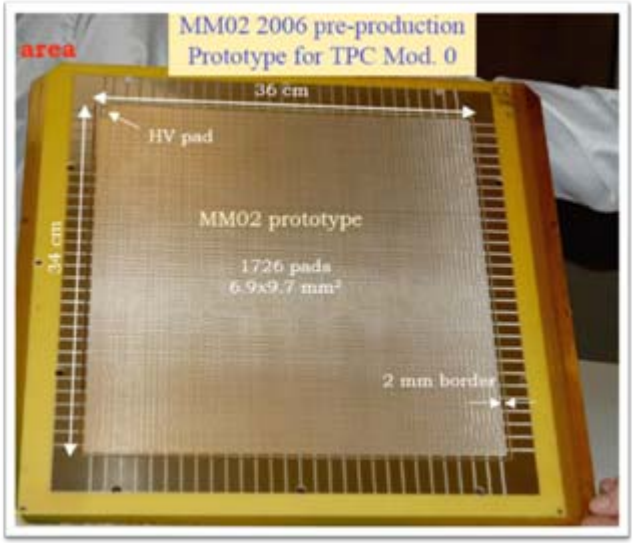


- **6 read-out planes (0.7x2.0 m^2)**
- **Maximum drift distance 1.0 m**
- **B=0.2 T E=200V/cm**
- **Pad size: 8x8 mm^2**
- **100000 channels**

95% Ar + 2% iC_4H_{10} + 3%CF_4
128 μm gap, gain 1000
^{55}Fe 5.9 keV FWHM = 19%

MicroMegas

Bulk MicroMegas technology gas amplification
12 modules (34 cm x 36 cm) on each TPC endplate

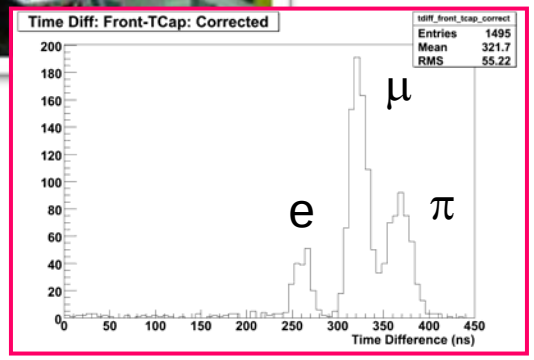


72 modules needed for 3 TPCs
48 MM modules produced
12 MM mounted on TPC #0 in November'08
12 more modules will complete TPC #0
in February 09

MicroMegas production started
in early 2008 $\rightarrow$ 8 per month.
Complete 84 by May 2009.

TPC # 0

TPC and FGD tests at TRIUMF

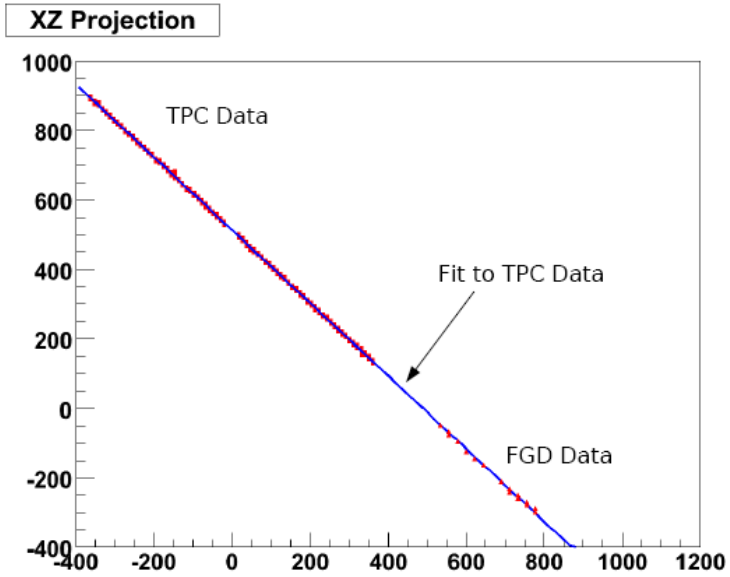


Mixed beam p,π,μ,e with momenta 100-400 MeV/c

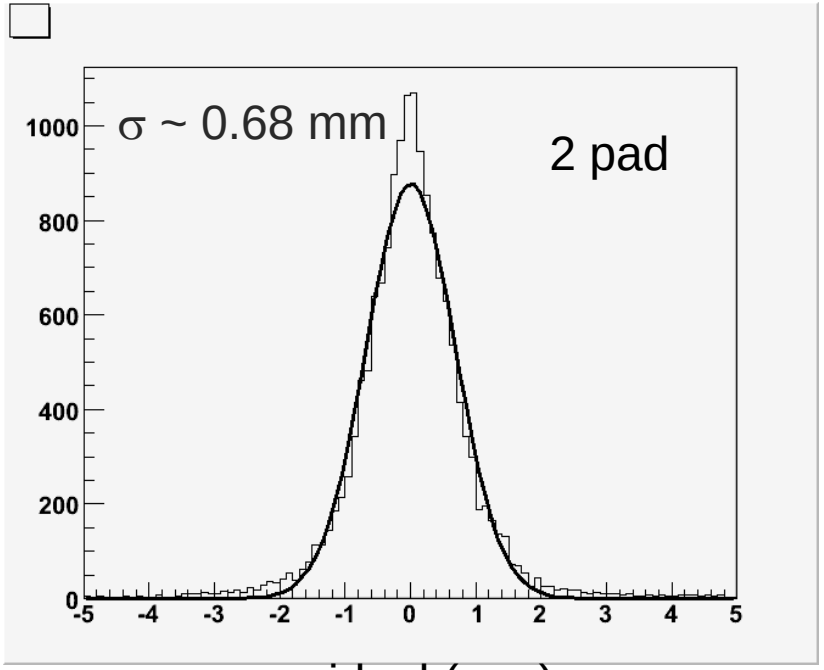
Tracker performance

T. Lindner

TPC+FGD: XZ Projection

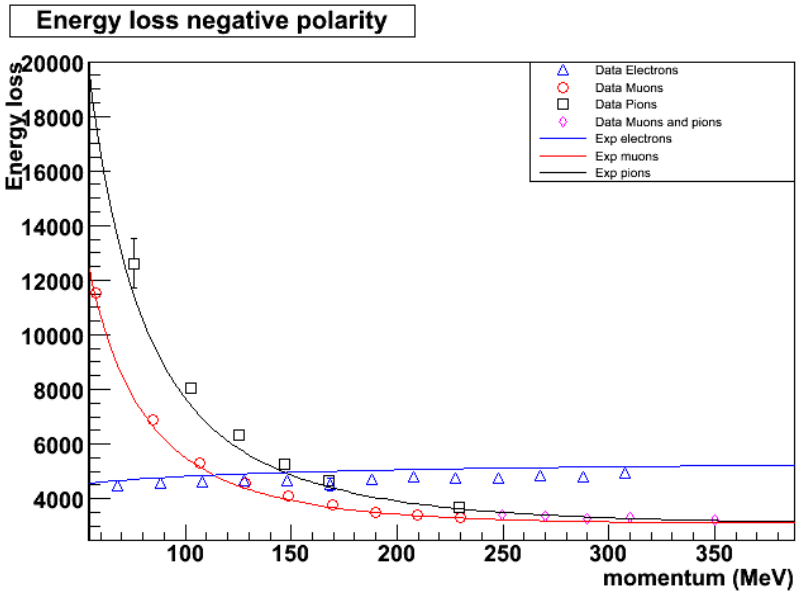


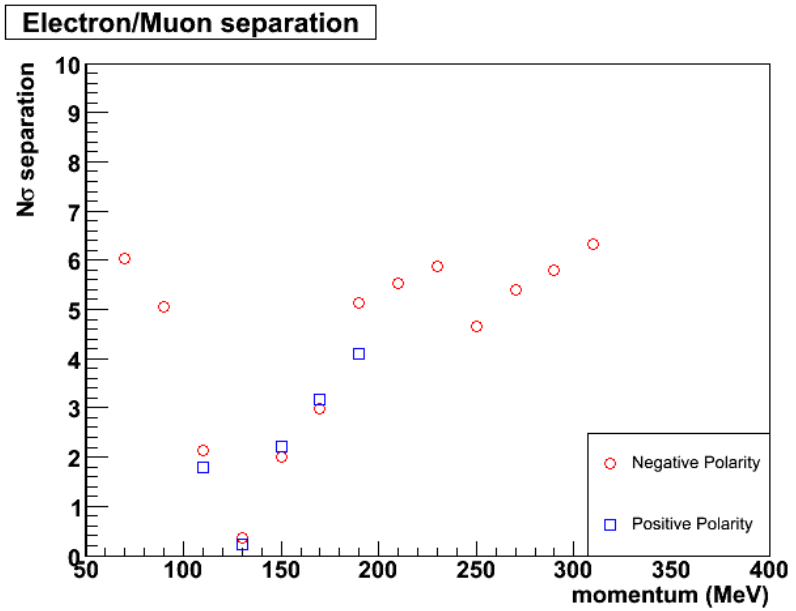
Micromegas spatial resolution



Typical widths for 2 pad clusters span
from 320 μm (15 cm drift length)
to 650 μm (75 cm drift length)

e / μ separation



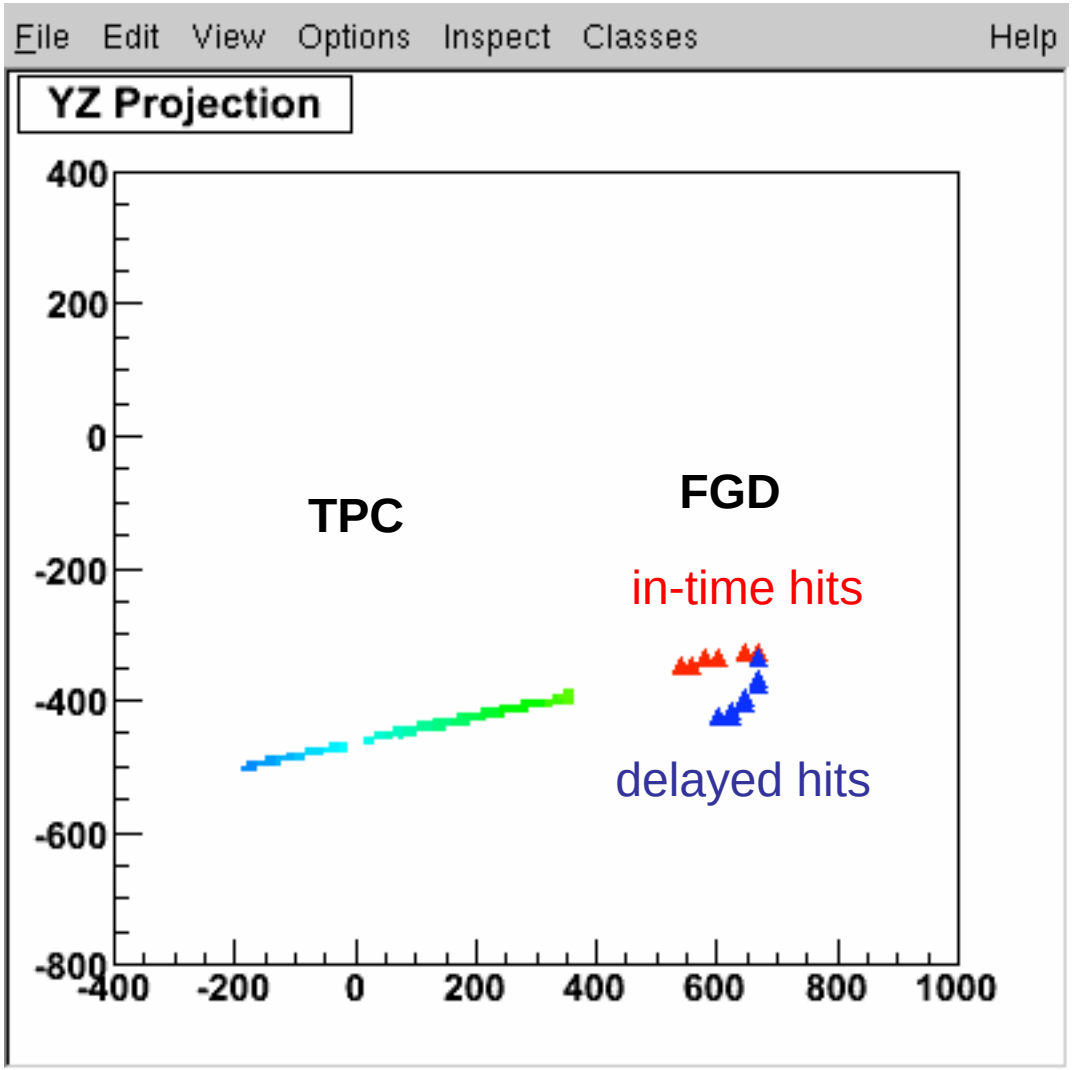


$$N(\sigma) = [dE/dx(\mu) - dE/dx(e)]/\sigma_{\mu}$$

~ 5σ separattion between muons and electrons for momenta > 200 Mev/c

TPC+FGD

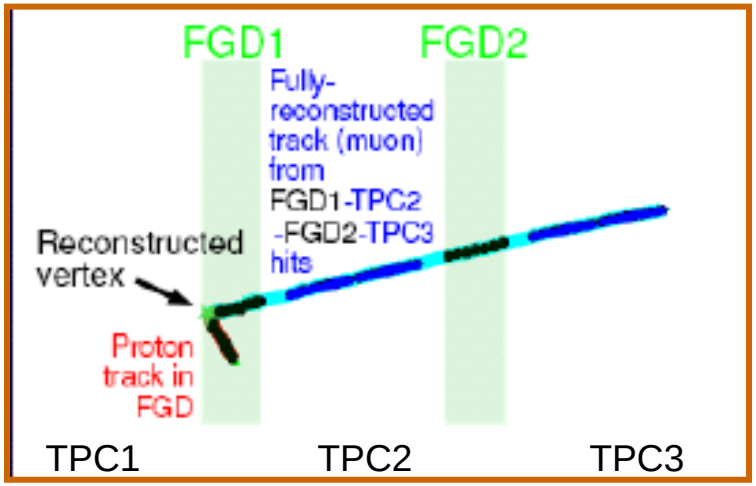
stopping track with decay electron

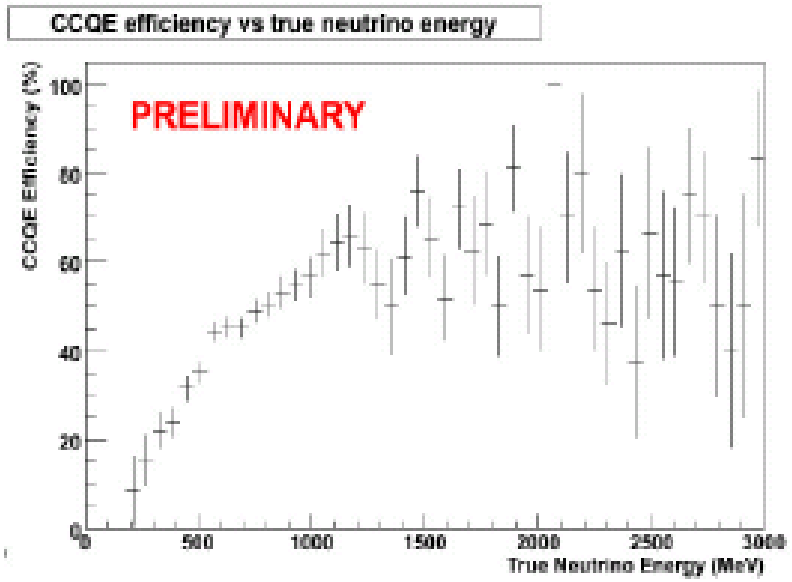


Tracking

Typical CCQE event in tracker

$\nu_\mu + n \rightarrow \mu^- + p$



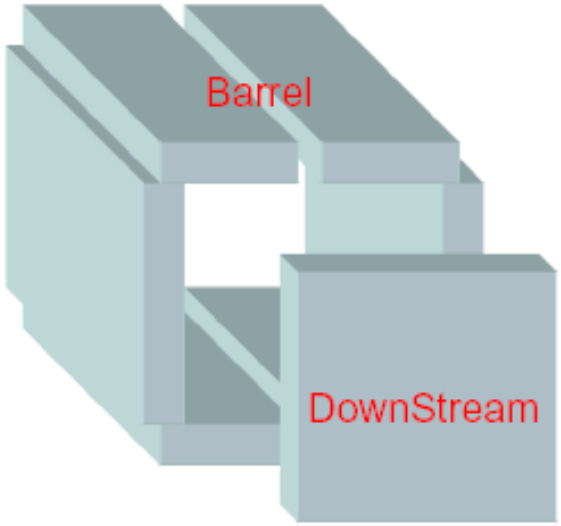


Eff (CCQE) ~50% at E_ν ~0.7 GeV

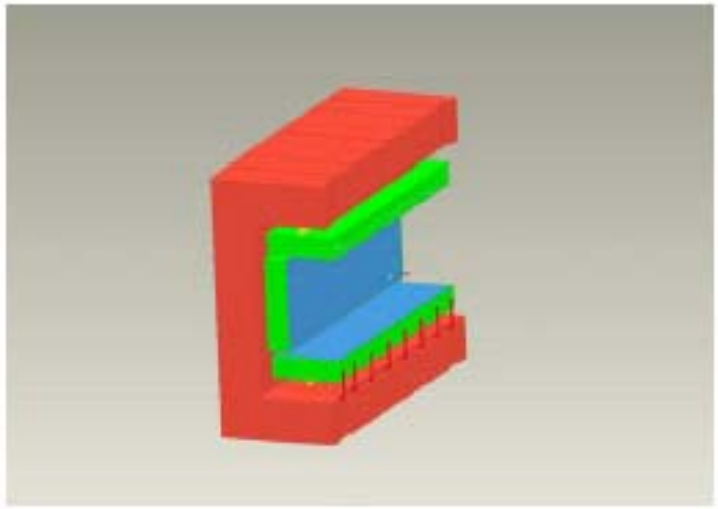
ECAL

ECAL functions:

π^0 reconstruction around tracker
charged particle identification
energy catcher around POD
incoming activity veto



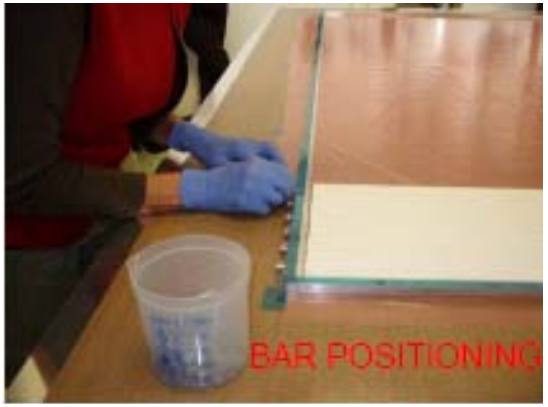
- **Ecal around tracker**
  - 6 sci layers
  - 5 Pb layers ($4.5X_0$)
  - 20 cm wide sci slabs
- **Ecal around POD**
  - 32 sci layers
  - 31 Pb layers, 1.75 mm each ($\sim 10X_0$)
  - 4cm wide sci slabs
  - crossed geometry
- **Downstream ECAL**
  - 37 Pb / 38 sci ($\sim 12X_0$)
  - crossed geometry
- **Readout**
  - WLS fibers
  - MPPC's ~20k devices

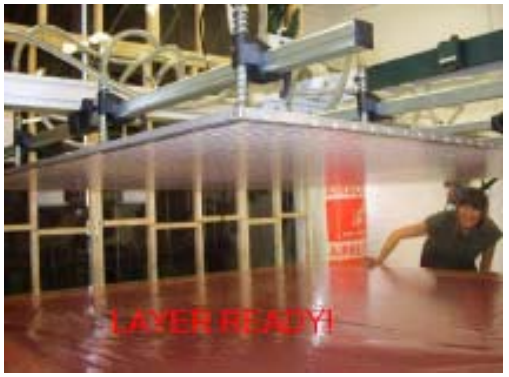


ECAL

Scintillator bar

2x2 m^2 DS
Ecal prototype

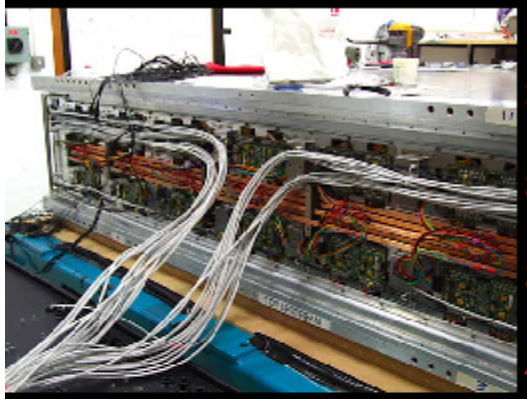




ECAL

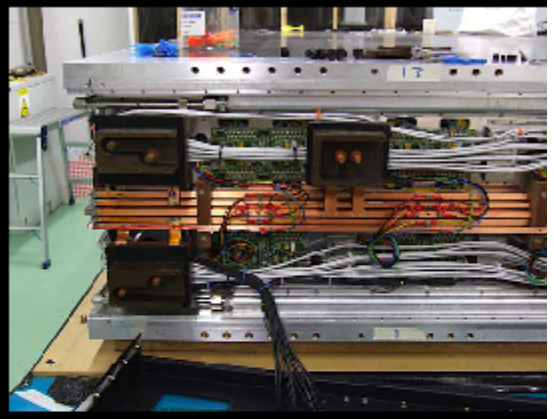
DS-ECAL (10-11/08, Lancaster)

1

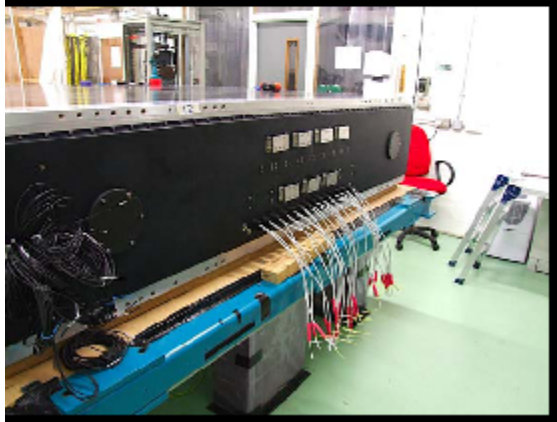


1. cabling
2. power distribution
3. completed
4. Support frame

2

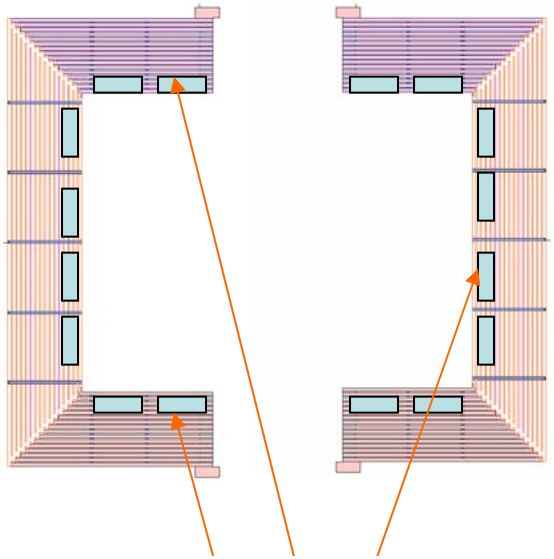


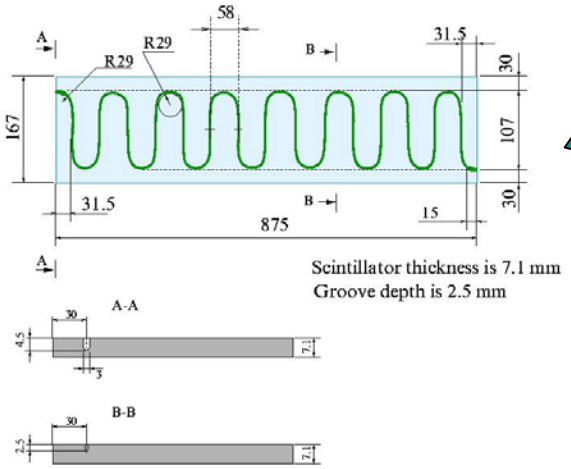
3



4

SMRD





Magnet yoke:

17 mm air gaps between iron plates

SMRD:

3-6 layers of the gaps instrumented with scintillator counters

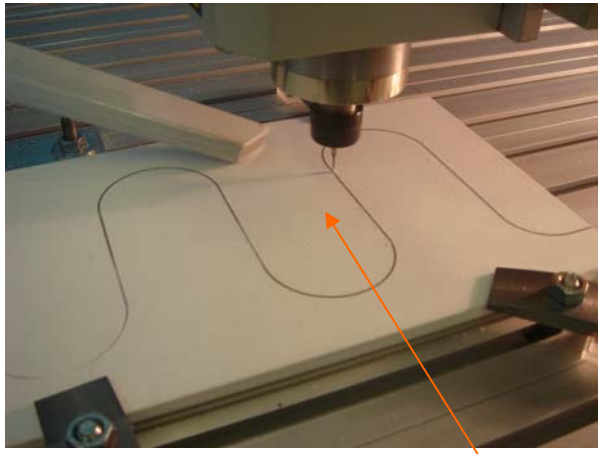
about 2000 counters

S-type configuration for fiber readout

both-end readout using MPPC's

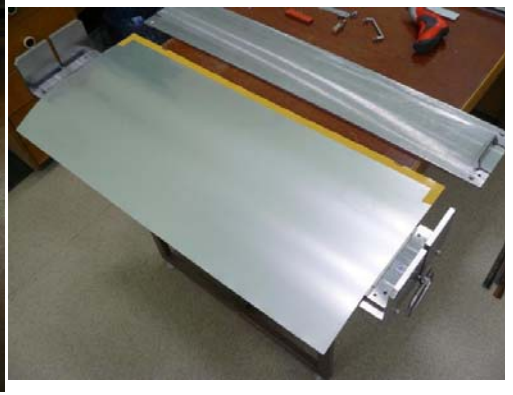
Scintillator counters
Length = 87 cm
Width = 17 cm
Thickmess = 7 mm
S-shape grooves
WLS fiber Y11
Both-end MPPC readout

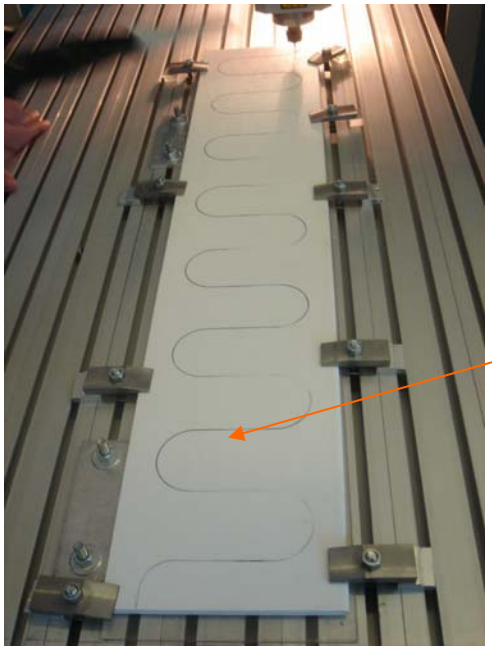
SMRD detectors



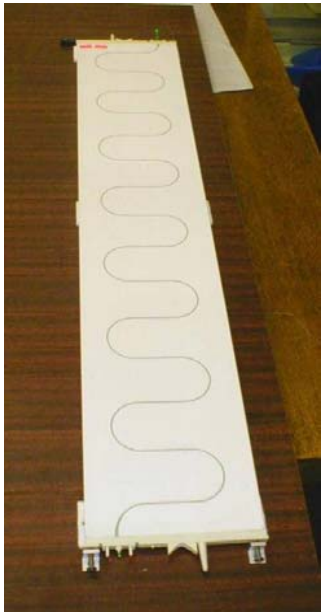
Y11 fibers embedded and glued

stainless steel container





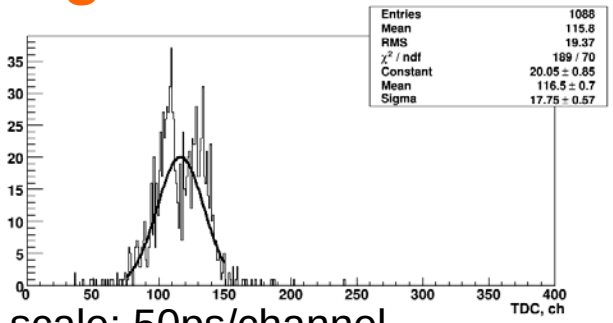
Preparation of S-grooves



Ready for shipment

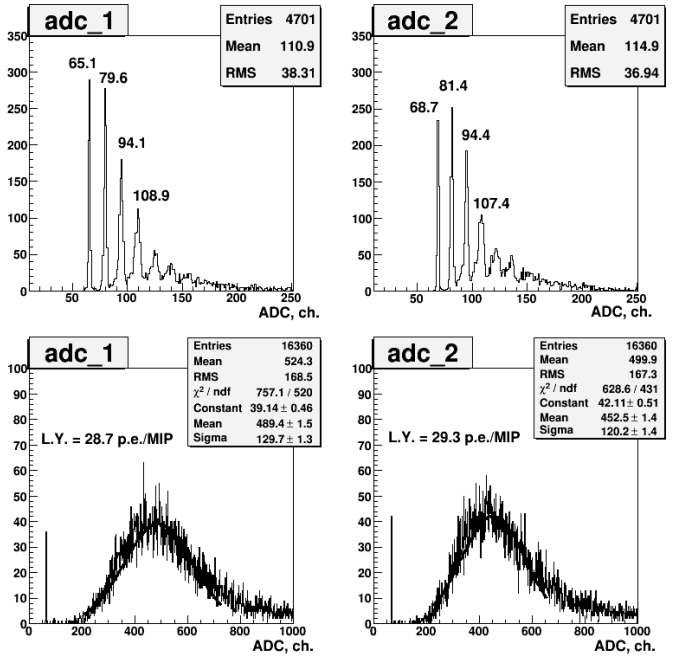
Test of SMRD counters

timing **cosmic muons** MPPC calibration **l.y.**



TDC scale: 50ps/channel

σ(MIP) ~1 ns



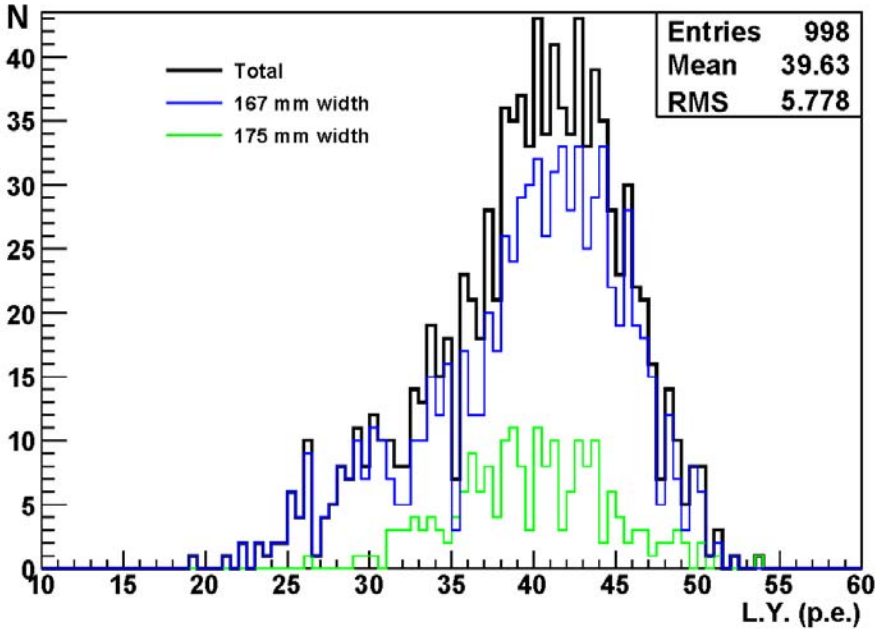
l.y. (sum of 2 ends) = 58 p.e./MIP

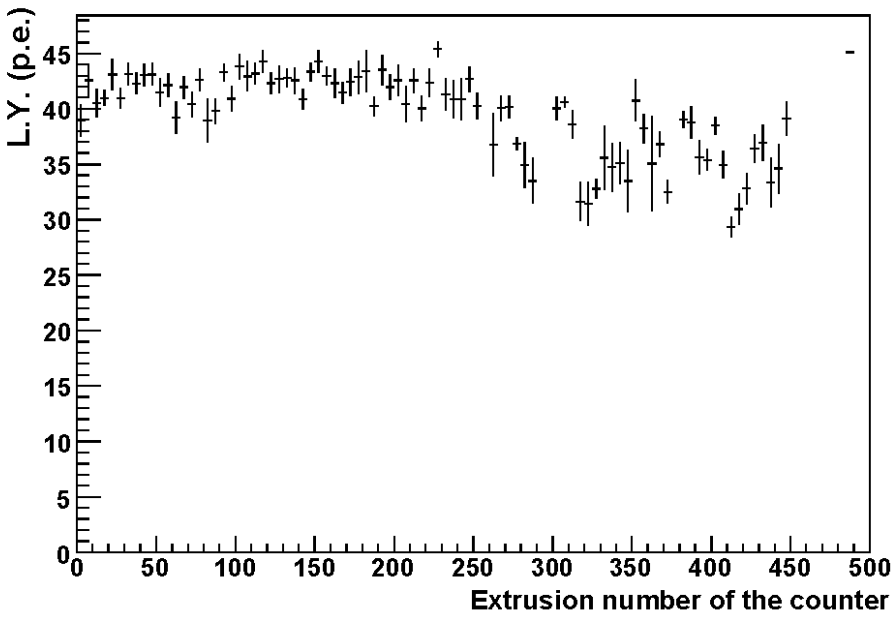
MIP detection efficiency	**> 99.9%**
Spatial resolution	**~ 7 cm**

Quality Assurance

1000 counters delivery to JPARC in Oct 2008
1130 will be completed in February 2009 → shipment to JPARC March 2009

Cosmic muon test: l.y. in center of counter sum of both ends





Excellent performance, MIP efficiency > 99%

Physics run

Data taking start December 2009

100kW, 30 GeV, 10^7 sec

$\nu_\mu \rightarrow \nu_e$ 3.7 events at CHOOZ limit

background 0.25 (ν_μ NC) 0.39 (beam ν_e)

$\nu_\mu \rightarrow \nu_\mu$ (FCFV μ -like)

	null oscillation	oscillation
All	183.2	64.4
CCQE	118.0	22.9
CC non-QE	58.7	35.1
NC	6.5	6.5

oscillation parameters

$\sin^2 2\theta_{23} = 1.0$

$\Delta m^2_{23} = 2.4 \times 10^{-3}$ eV^2

L = 295 km

Summary

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

Neutrino beam **April 2009**

muon monitor and INGRID (1 module) will be ready for neutrino beam commissioning

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

installation in UA1 magnet

Physics run **December 2009**

ND280m starts data taking for oscillation and non-oscillation physics