The near Detectors (ND280) of the T2K neutrino long baseline experiment

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Outline

- Neutrino Physics introduction
- Overview of the T2K physics
  - experiment + measurements
- The T2K near detectors
  - On-axis detector
  - Off-axis detector
- Summary and Outlook

Neutrino mixing

Flavor   Mass

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

SK, K2K, MINOS
$\theta_{23} \approx 45^o$
$\Delta m^2_{23} \sim 2.7\times10^{-3}$ eV^2

CHOOZ
$\theta_{13} < 12^o$

δ is unknown

Solar, KamLand
$\theta_{12} \approx 32^o$
$\Delta m^2_{23} \sim 8\times10^{-5}$ eV^2

Mixing	Quarks	Leptons
1-2 θ_{12}	13^o	32^o
2-3 θ_{23}	2.3^o	45^o
1-3 θ_{13}	$\sim 0.5^o$	$<12^o$

Physics Motivation

- Sizes of neutrino mixing angles θ_{23}, θ_{13}, δ ?
  - Symmetry of 2nd and 3rd generation ?
    - E.g. how close is θ_{23} to $\pi/4$?
  - How small is the mixing of 1st and 3rd generation ?
    - Does $\nu_\mu \rightarrow \nu_e$ exist ? Does ν_3 contain ν_e ?
  - Do sterile neutrinos exist ?
    - Fraction in disappearance of ν_μ
  - How large is the phase δ ?
    - CP violation in the neutrino sector ?
  - What does the ν mass hierarchy look like ?
    - How large are matter effects ?

- High precision measurements to look for unexpected

Measurements

Oscillation Probabilities

$\Delta m^2_{12} << \Delta m^2_{23} \approx \Delta m^2_{13}$

- ν_μ disappearance

$P(\nu_\mu \to \nu_\mu) \approx 1 - \cos^4\theta_{13} \sin^2 2\theta_{23} \sin^2(1.27 \Delta m^2_{23} L/E_\nu)$

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$\approx$

- ν_e appearance

$P(\nu_\mu \rightarrow \nu_e) \approx \sin^2\theta_{23} \sin^2 2\theta_{13} \sin^2(1.27 \Delta m^2_{13} L/E_\nu)$

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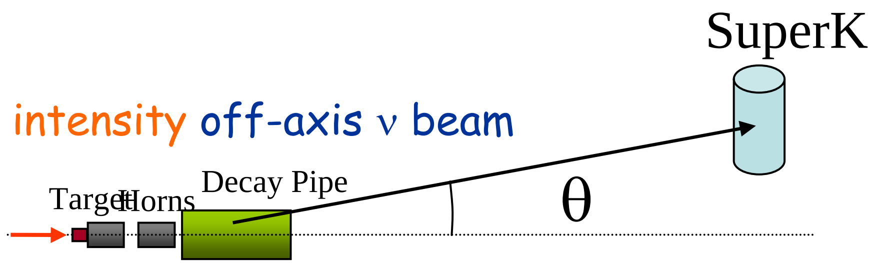
- δ ~~CP~~ in ν_e appearance

$$A_{CP} = \frac{P(\nu_\mu \to \nu_e) - P(\bar{\nu}_\mu \to \bar{\nu}_e)}{P(\nu_\mu \to \nu_e) + P(\bar{\nu}_\mu \to \bar{\nu}_e)} \approx \frac{\Delta m^2_{12} \sin 2\theta_{12}}{4\, E_\nu \sin\theta_{13}} \sin\delta$$

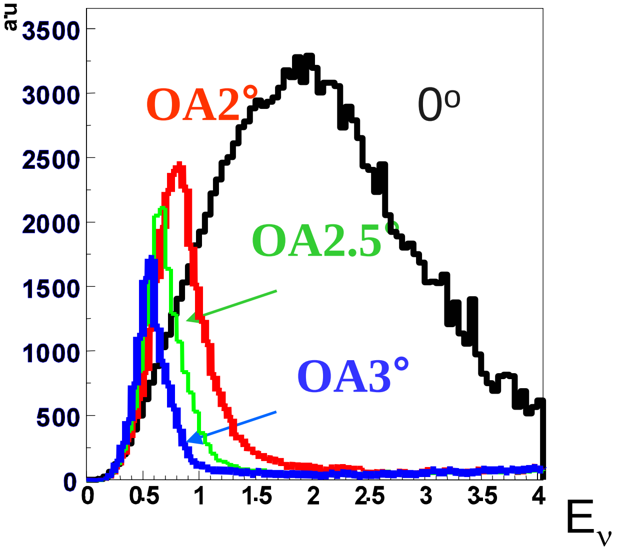
T2K strategy

- High intensity off-axis ν beam



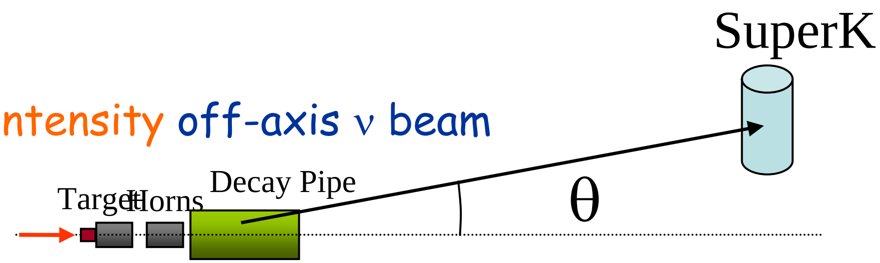
→ Narrow energy spectrum

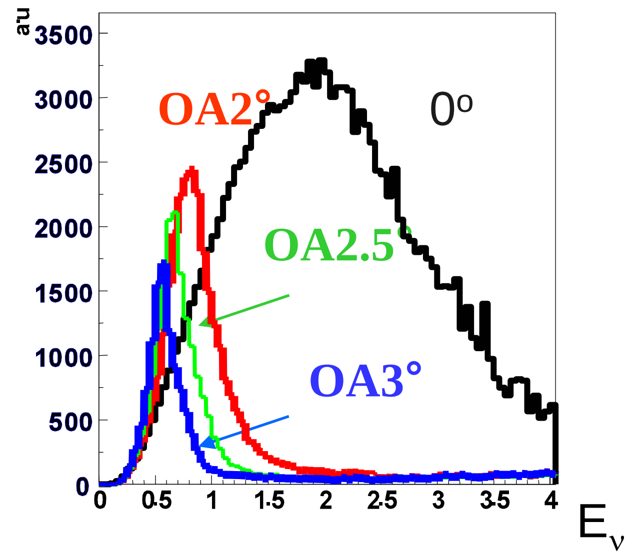
Choose E_ν at oscillation maximum for $L \approx 300$km



T2K strategy

High intensity off-axis ν beam





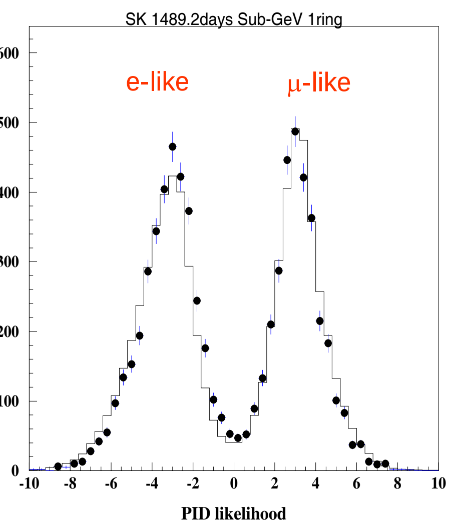
→ Narrow energy spectrum

Choose E_ν at oscillation maximum for L≈300km

Sub-GeV ν suited for water Cherenkov detection

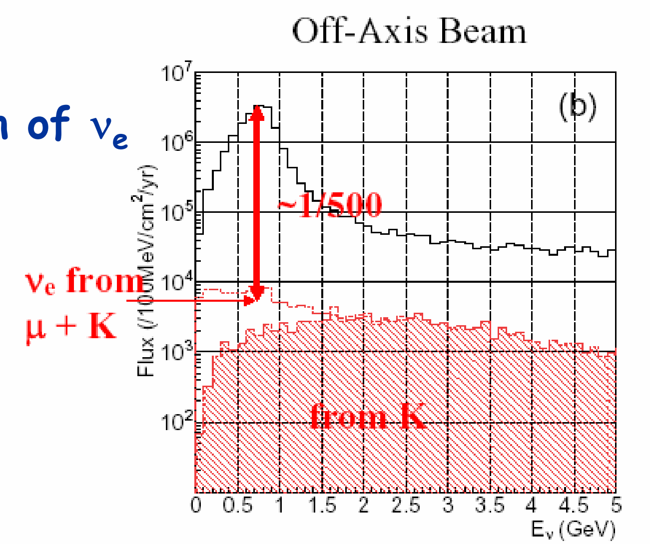
dominated by CC-QE: ν + n → μ + p

Good E_ν reconstruction; μ, e identification



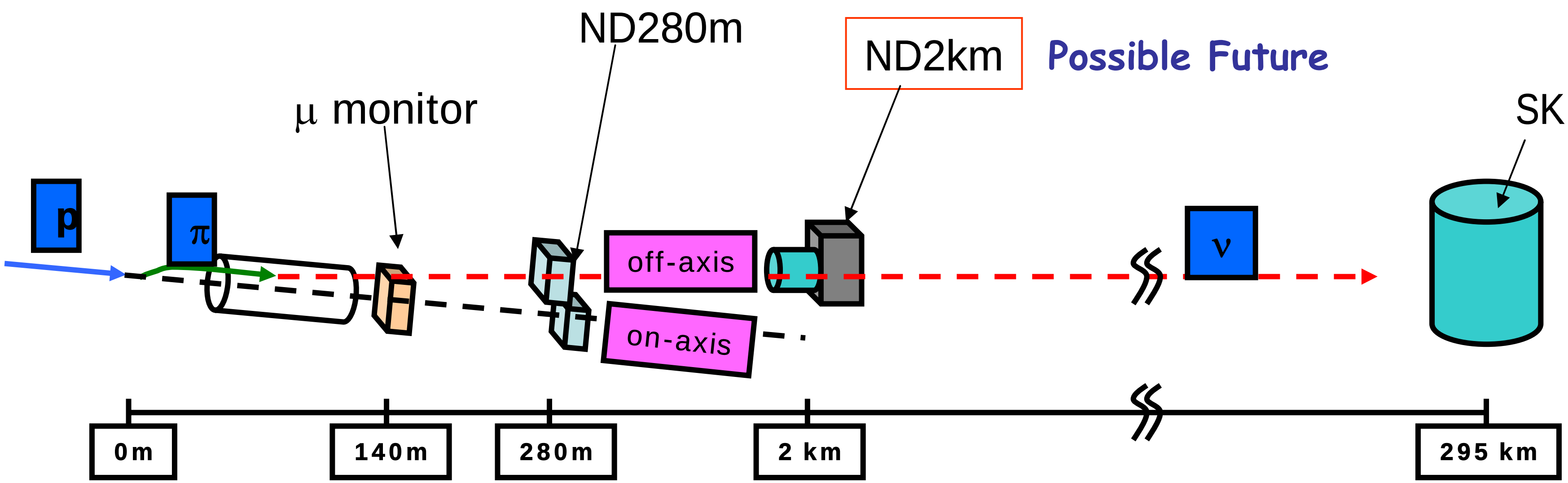
PID at SK in ν_e search (K2K)

small contamination of ν_e



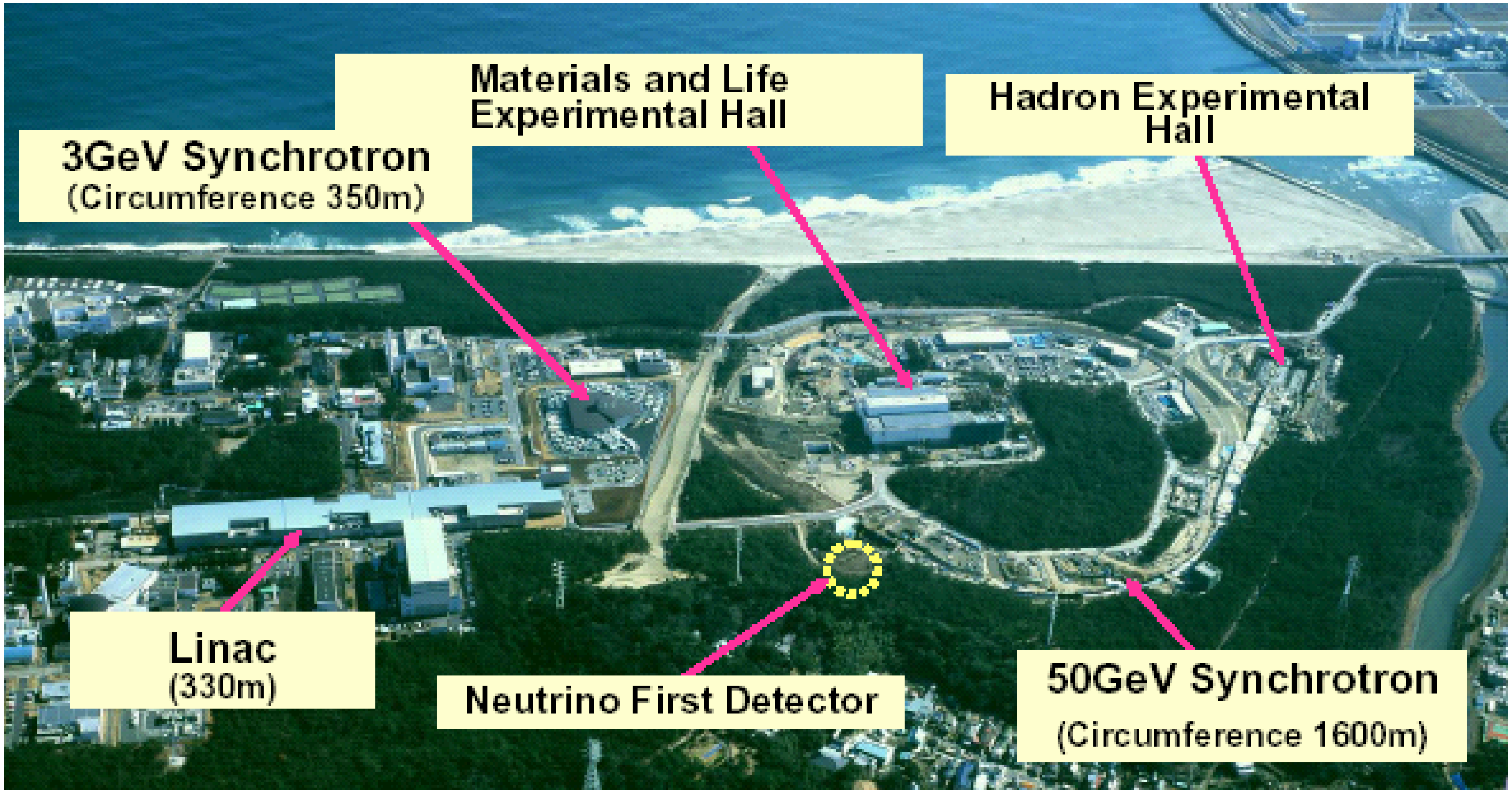
Intrinsic background: ν_e / ν_μ (peak) ~ 0.002

T2K Overview



- Muon monitors at ~ 140m
  → spill-by-spill monitoring of π beam direction and intensity
- Near detector at ~ 280m
  → 0° definition
  → E_ν, π^0 production
- Intermediate detector at ~ 2km (possible future extension)
  → ultimate systematics
- Far detector at 295 km
  → Super-Kamiokande (50 kton)

JPARC



	T2K	K2K	NUMI
E (GeV)	50	12	120
Int. (10^{12} ppp)	330	6	40
Rate (Hz)	0.29	0.45	0.53
Power (MW)	0.75	0.005	0.41

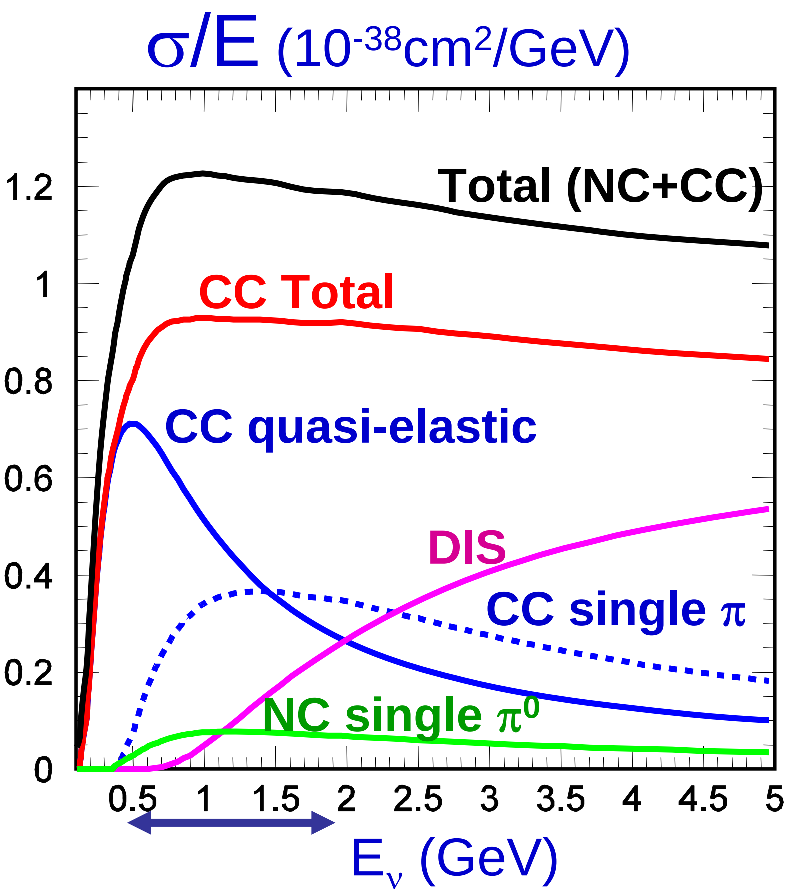
400 MeV Linac (200 MeV)
1 MW 3 GeV RCS
0.75 MW 50 GeV MR (30GeV)

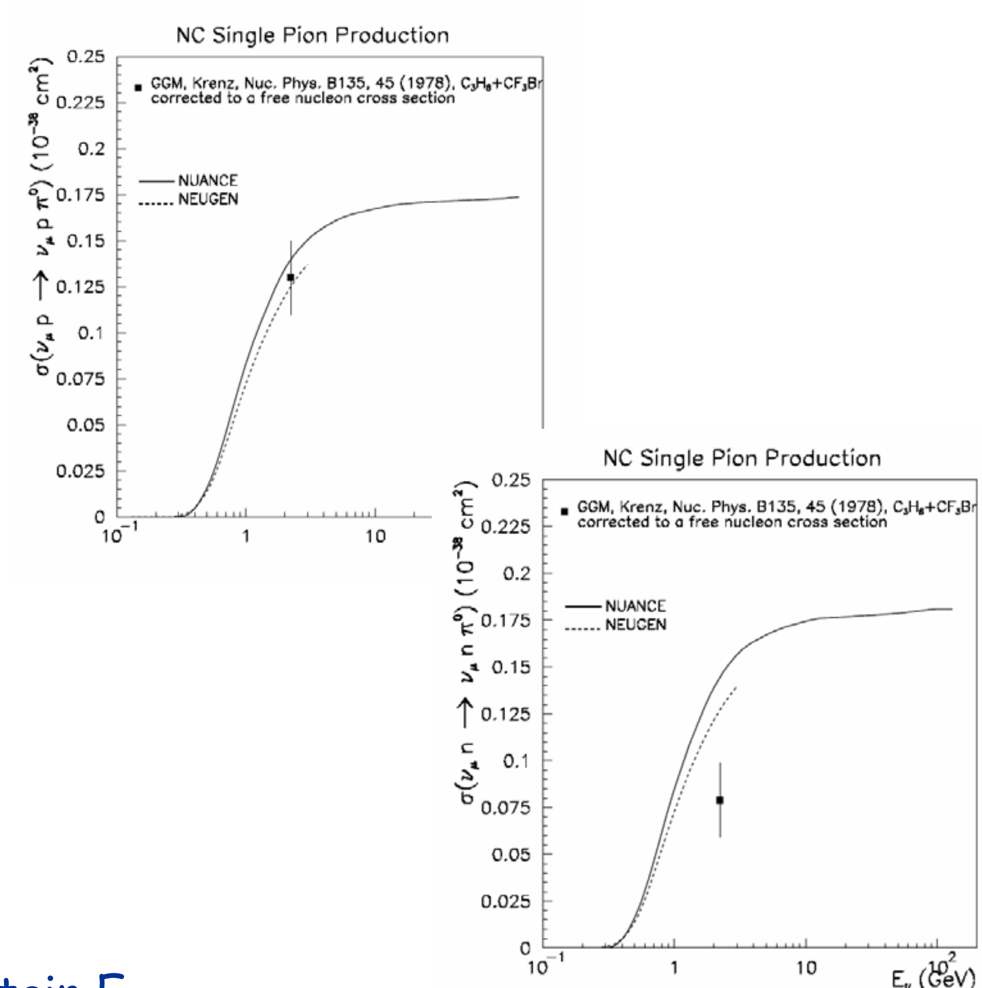
$\sim 1 \times 10^{21}$ pot / year

T2K Collaboration

11 countries, 58 institutions, ~200 collaborators

NEUT: Neutrino interaction MC





- Info from CC-QE lepton enough to obtain E_ν
- backgrounds: CC single π events where π is missed (e.g. below threshold)
  → smears out E spectrum
- π^0 production and only one photon is detected

Sensitivity ν_e appearance

dominant background sources:

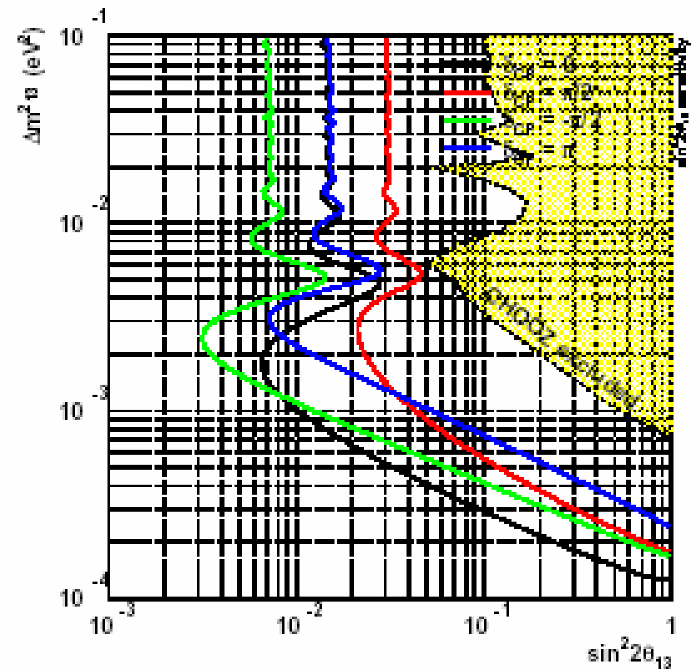
- beam ν_e contamination
- NC single π^o production

Assume: 5×10^{21} POT $\Delta m^2_{23}=2.5\times10^{-3}$ $\sin^2 2\theta_{23}=1$

$\sin^2 2\theta_{13} \approx 0.01$ sensitivity (90% C.L.)

requires <10% in background uncert.

$\delta_{CP} = 0$ (black line)
$\delta_{CP} = \pi/2$ (red line)
$\delta_{CP} = -\pi/2$ (blue line)
$\delta_{CP} = \pi$ (green line)



Sensitivity

ν_μ disappearance

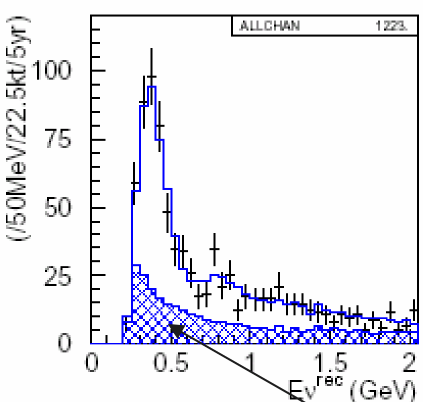
Requirements for systematics

Energy scale	2%
Non-QE/QE	5-10%
Neutrino flux	<5%
Spectrum width	10%

assume

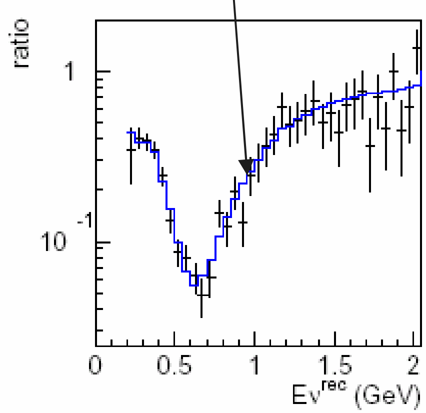
5×10^{21} POT $\Delta m^2_{23}=2.5\times10^{-3}$ $\sin^2 2\theta_{23}=1$

Reconstructed E_ν spectrum

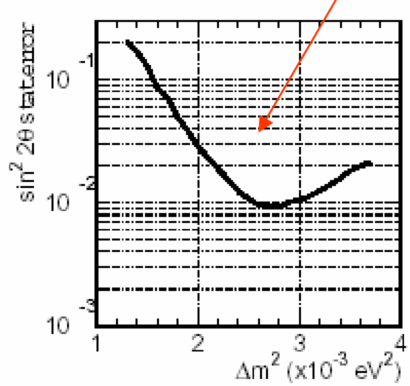


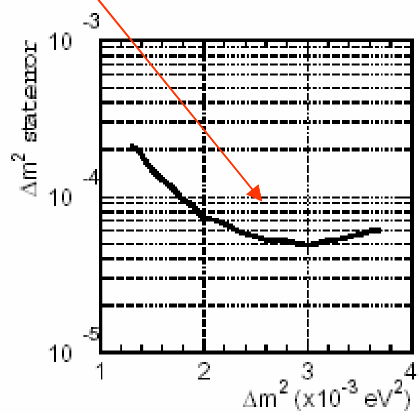
Non-QE

oscill/(w/o oscill)



Expected stat errors





$\delta(\Delta m^2_{23})=5\times 10^{-5}\ \mathrm{eV}^2$ $\delta(\sin^2 2\theta_{23})=0.001$

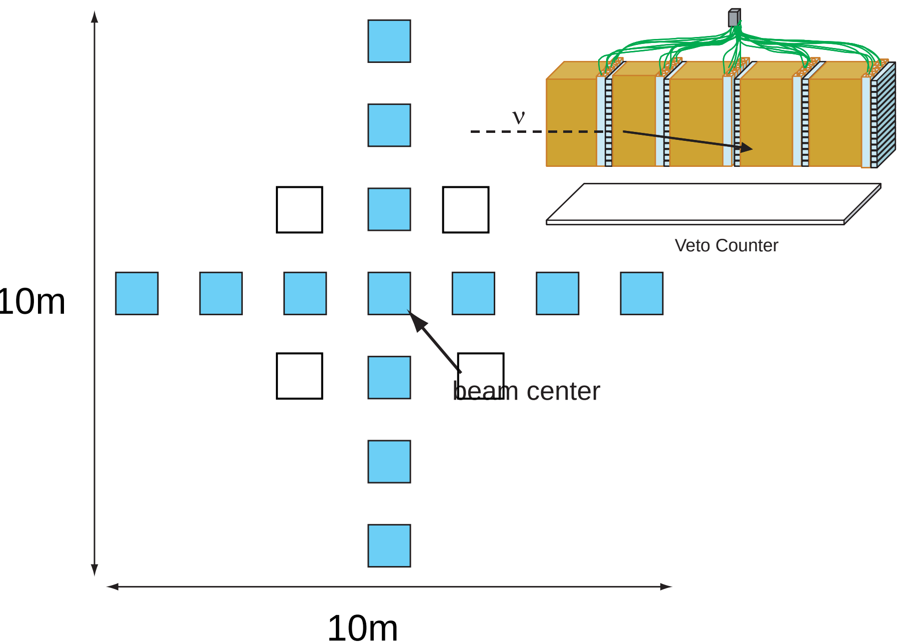
Requirements for Near Detectors

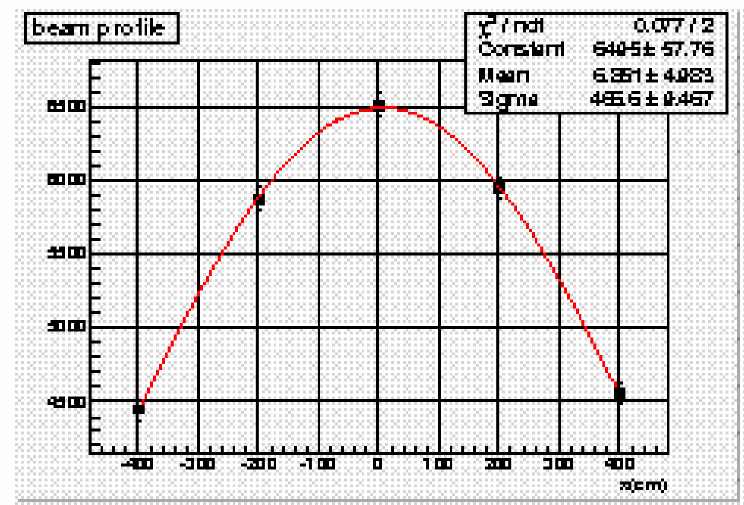
- **Basic Idea:** Predictions of ν flux and interactions at far Detector

→Neutrino spectrum at far detector is predicted based on neutrino spectrum at ND280 and corrections (Far/Near ratio)

- Measurements of neutrino interactions in water target
- **Profile of ν beam → determination of off-axis angle (on-axis detector)**
    - Neutrino beam direction accuracy <<1 mrad
- ν_μ **and ν_e fluxes, charged current processes (tracking detectors)**
    - $\nu_\mu\ n \rightarrow \mu^-\ p$ CCQE $E_\mu \leq 1$GeV, θ_μ = 0 – 180 deg
    - Muon momentum scale uncertainty 2%
    - Fermi motion → Muon momentum resolution 10%
    - Neutrino flux measurement at ND280 with accuracy 5%
    - $\mu+/\mu-$ identification
- **backgrounds**
    - π^0 production cross sections (**Pi-Zero, Ecal**)
    - Measurement of ν_e contamination with 10% uncertainty
    - Detection of recoil protons
    - Charged pion measurement

ND280m On Axis Detector





purpose: monitor direction of ν beam with ν on daily basis

Precission: required < 1mrad (=2% in E_ν); simulated performance: ~0.1 mrad

Yield, Profile, Longterm stability

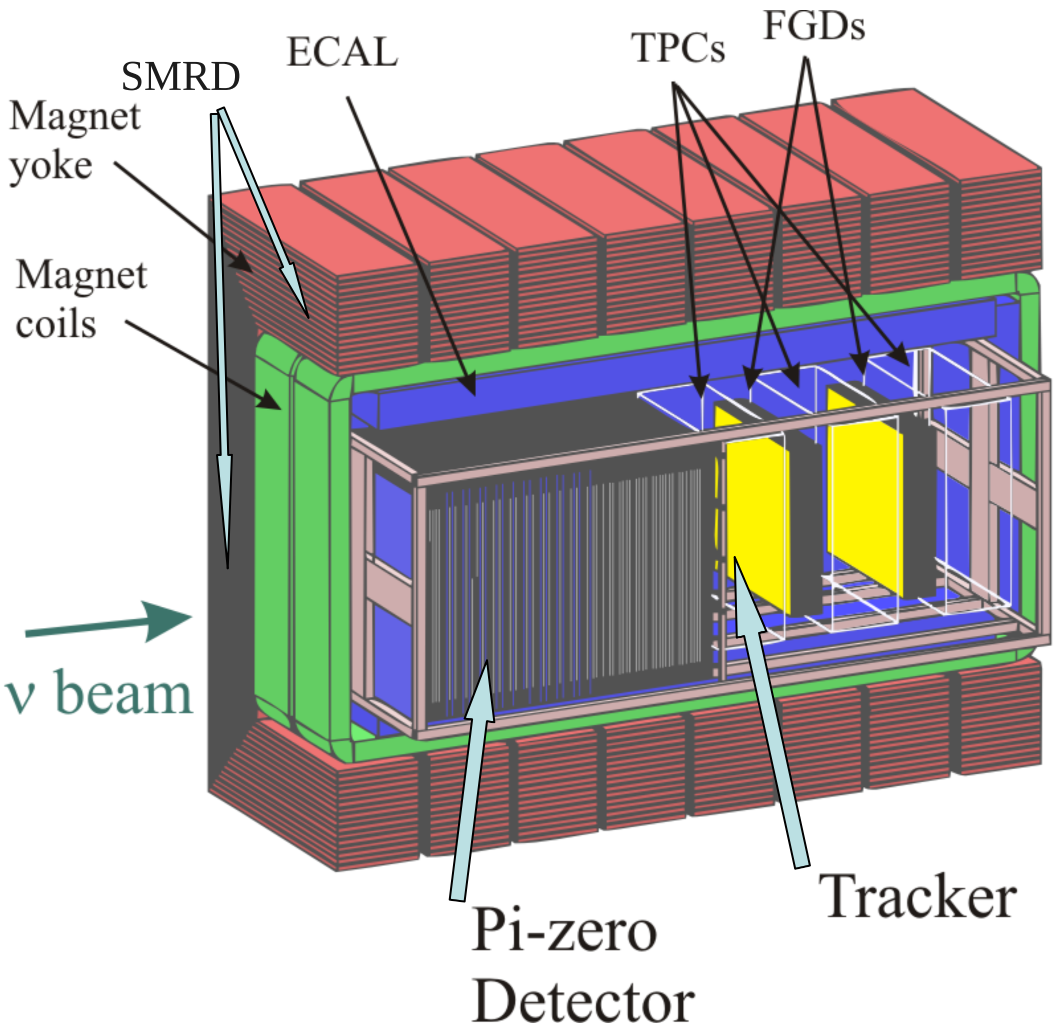
⇒ robust, stable and massive neutrino monitor
to cover a wide region of the beam profile

Technology: sandwiched tracking scintillator and iron planes,
surrounded by veto; ~8 tons → ~10000 events per day after cuts

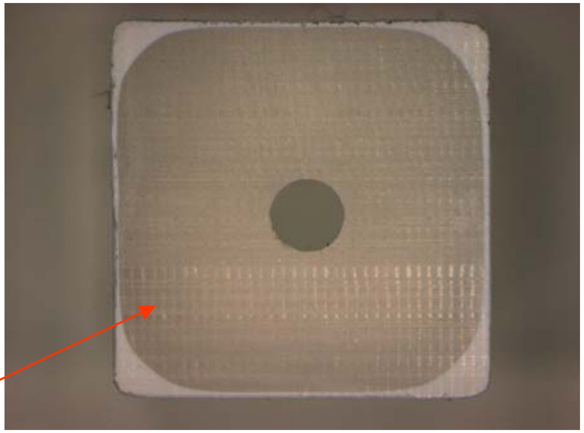
ND280m Off-axis Detector

Design:

- UA1 magnet
  - B field: 0.2 T
  - inner volume: $3.5 \times 3.6 \times 7.0\ m^3$
- Tracker
  - Optimized for CC studies
- Pi-Zero
  - Optimized for π^0 from NC
- ECAL
  - Photon detection (from π^0)
- SMRD
  - Lateral muons, CR trigger



Tracker: Fine Grained Detector (FGD)



Purpose: measure ν beam flux, E_ν spectrum, flavor composition through CC ν-interactions, backgrounds CC-1π

Two FGD's (based on K2K Scibar design)

1st: x-y layers of scintillators (~1 ton)

2nd: passive water layers (~0.4 tons) interspersed with x-y scintillator layers (~0.55 tons)

Size of FGD 1: 30 layers of 192 scintillator bars each with 1cm x 1cm scintillator bars with 1mm diameter Y11 WLS fiber

2: 7 x-y layers alternating with 2.5cm thick water layers

Total weight 1.0 ton/FGD

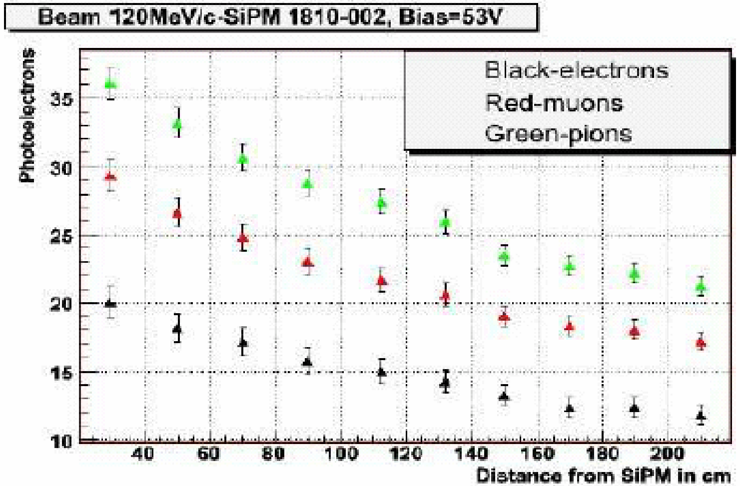
Thickness 0.3 m → to make particles get out of FGD into TPC, especially for pions, to measure their momentum before interacting with materials

Cell size 1 cm ; particle ID from dE/dx lower particle detection threshold for protons down to 200 MeV/c

Readout WLS fiber Y11, one end by multi-pixel Si APD's

Electronics accept late hits from Michel e^-

Possible future upgrade: water-based scintillator

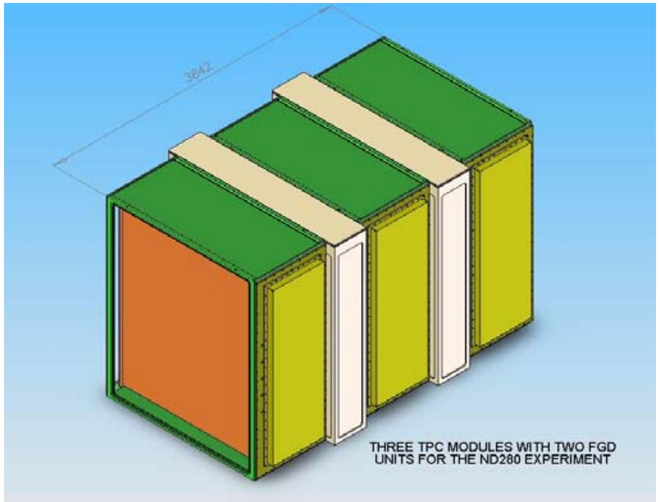


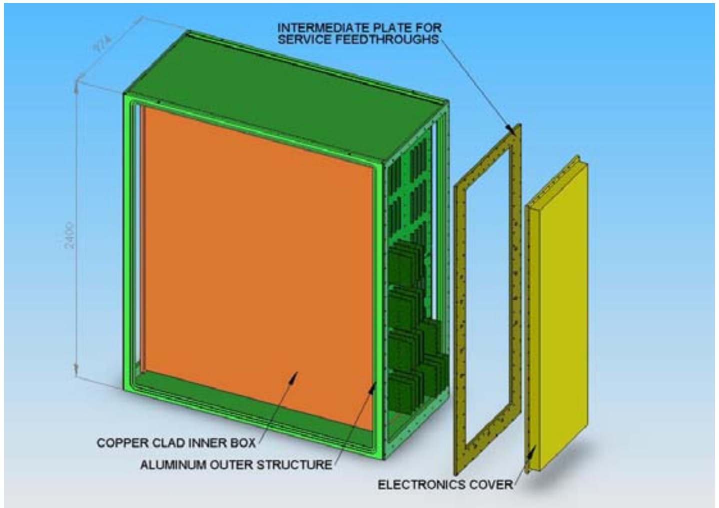
Tracker: Time Projection Chamber (TPC)

Purpose: measure charged particle momenta, particle ID via dE/dx,
measure backgrounds/pion cross section

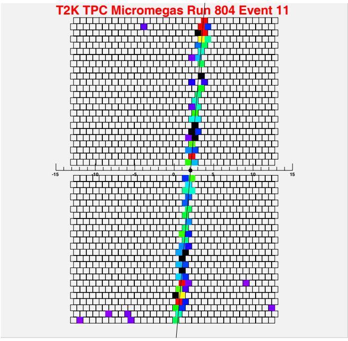
3 Ar gas TPC modules: 2.5m x 2.5 m x 90 cm   Target: FGDs

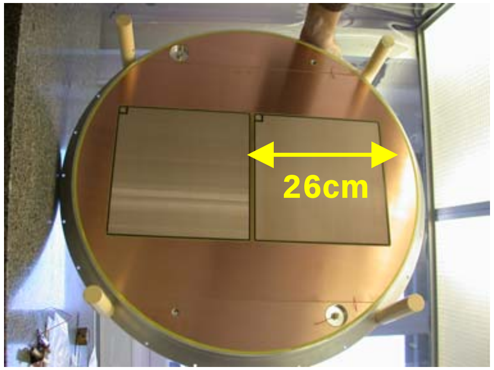
Precission requirements:
10% momentum resolution at ~1GeV → space point resolution
2% in muon momentum scale (main systematics in ν_μ disappearance)
<10% for dE/dx measurement





Gas amplification Micromegas



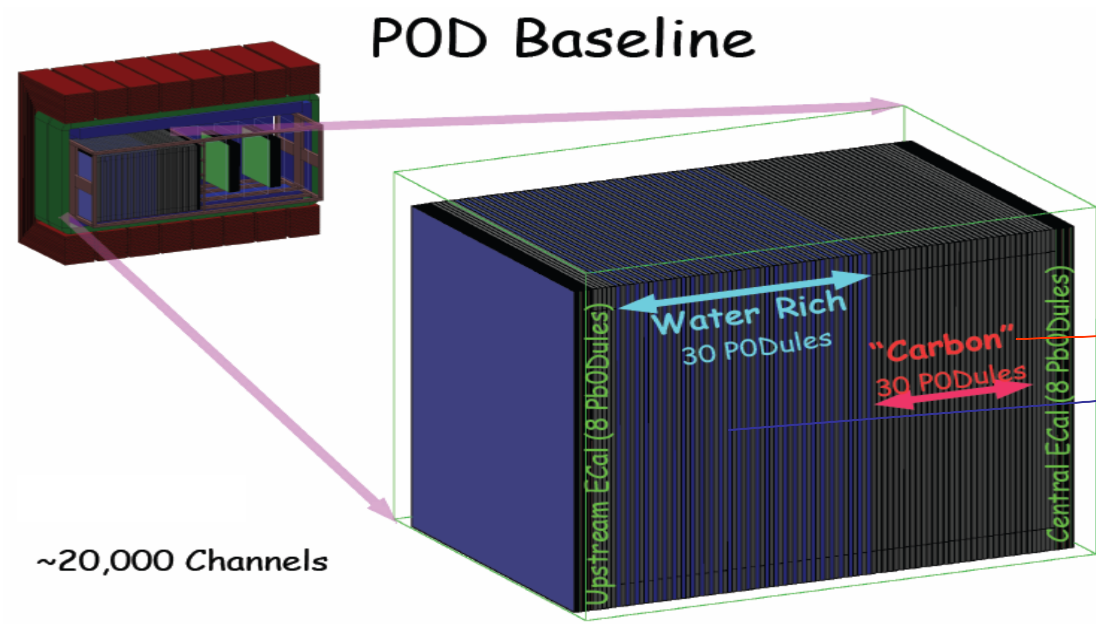


- 6 read-out planes ($0.6x2.5\ m^2$)
- Total drift distance 1.25 m
- B=0.2 T E=200V/cm
- Pad size: 0.6 to 0.8 cm
- ~100k channels

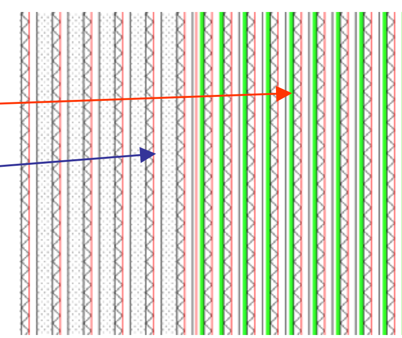
Pi-Zero Detector (P0D)

Purpose: NC π^0 measurement
measure ν_e contamination

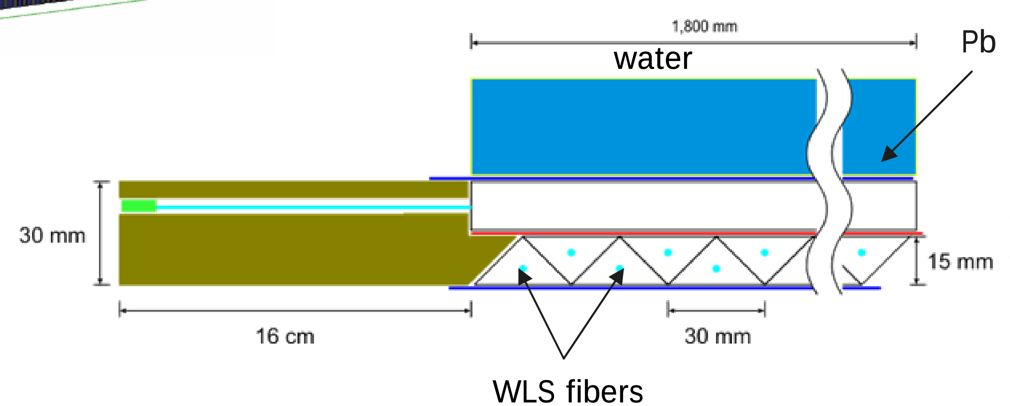
Precission: 1.7 x 10^4 NC single π^0 events in water target for 10^{21} POT (1 year)
efficiency for π^0 reconstruction 50-60%



Size:
Approx volume 2 x 2 x 3 m^3
Total mass ~19 t
Fiducial ~6 t
H20 target ~1.7 t



POD layer:
- co-extruded triangular polystyrene bars with TiO_2 reflective layer
- central hole with WLS fiber
- thin (0.6 mm) lead sheets

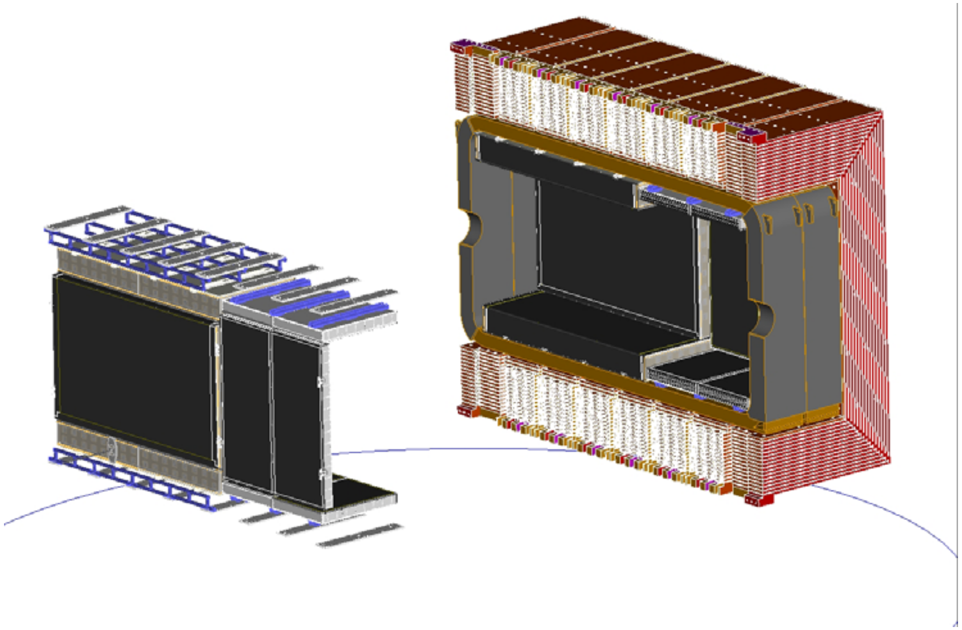


Electromagnetic CALorimeter (ECAL)

Purpose: π^0 reconstruction around tracker, charge particle ID and reconstruction

3 ECAL parts: all are sandwich lead and scintillator (10mm) layers

1. around tracker: 32 active, 31 Pb layers (1.8mm), 28.5 tons, ~$10X_0$
2. Around POD: coarser segmentation; 6 active, 5 Pb layers(5mm); 4.5 X_0
3. Downstream: 50cm thick; 34 active layers, 33 Pb layers ; 4.2 tons; ~$10X_0$

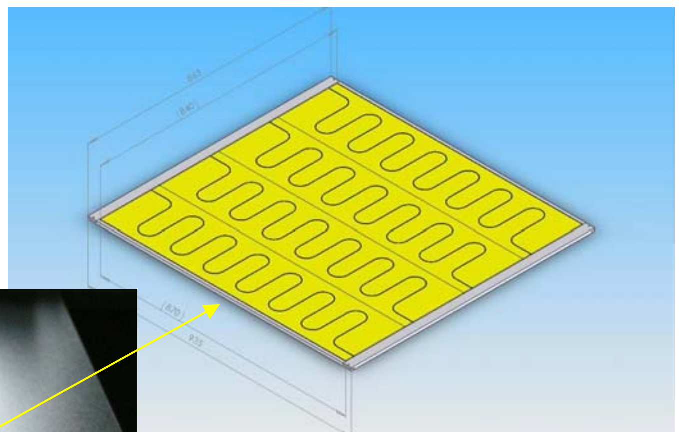


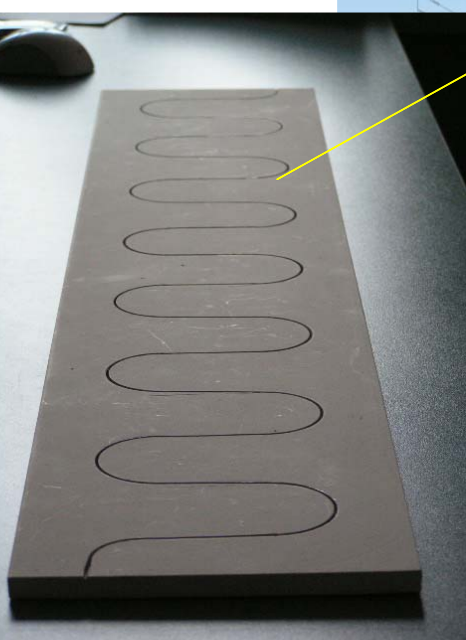
Dimensions:
Scintillators with central and embedded
S-shape Type fiber
readout: micro-pixel Si APDs

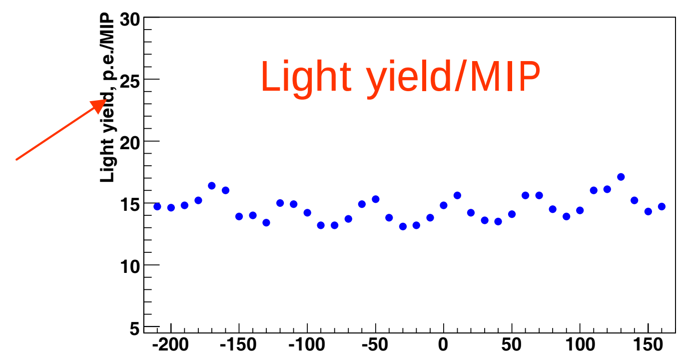
Side Muon Range Detector (SMRD)

Purpose: measure momentum for lateral muons, provide trigger on cosmic rays
Magnet yoke: 17x870x700 mm³ air gaps between iron plates
SMRD: ~5 layers of gaps instrumented with scintillator slabs; ~3000 slabs
→ range out ~95% of lateral muons
S-type configuration for fiber readout

Beam test with 1.4 GeV/c pions	
Light yield	15-20 p.e.
Timing (σ_t)	1.5 - 2.0 ns
space resolution	10-11 cm
efficiency (MIP)	> 99%

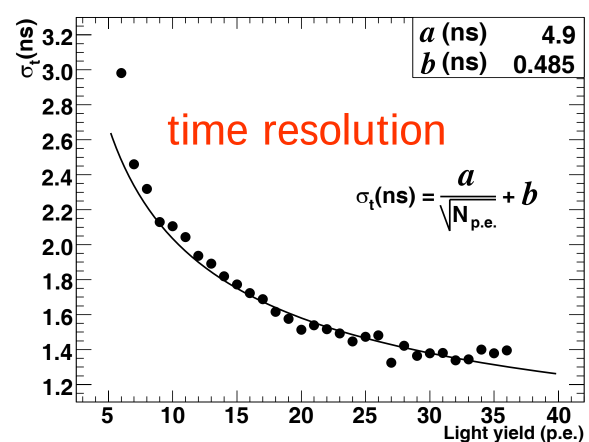






Scintillator dimension:
Length = 87 cm
Width = 17 cm
Thickmess = 7 mm

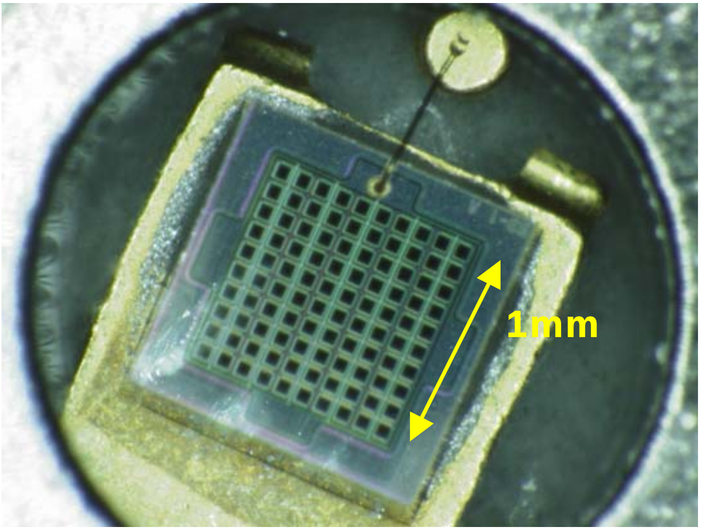
S-shape grooves
Depth 4 mm
Length ~ 2.5 m
Y11, double clad,1mm diameter
readout: micro-pixel Si APDs on both ends



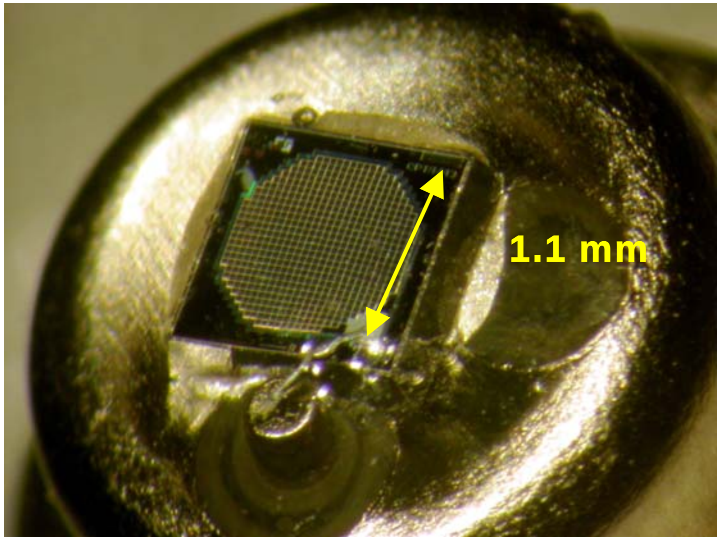
Photosensors

ND280m: ~ a few 10^5 m WLS fibers → > 10^5 photosensors
Individual fiber readout, magnetic field and limited space
Compact multi-pixel Si APD's operating in limited Geiger mode

MPPC (Hamamatsu,Japan)
100/400 pixels



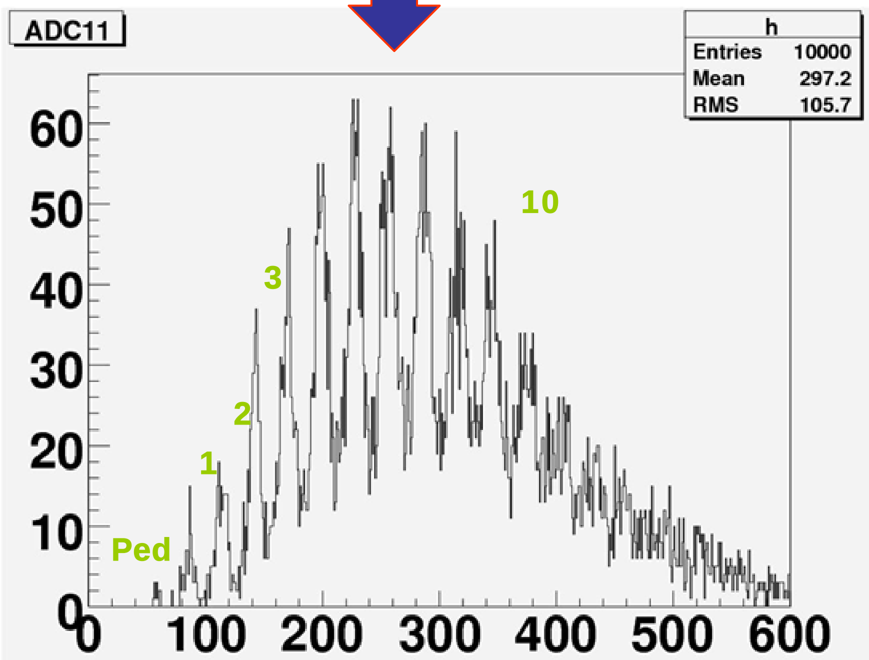
MRS APD (CPTA, Moscow)
556 pixels



Active area	1.0-1.2 mm^2
Gain	~10^6
PDE	10-16%
Bias voltage	25-70 V
Dark rate	≤ 1MHz (th = 0.5 p.e.)

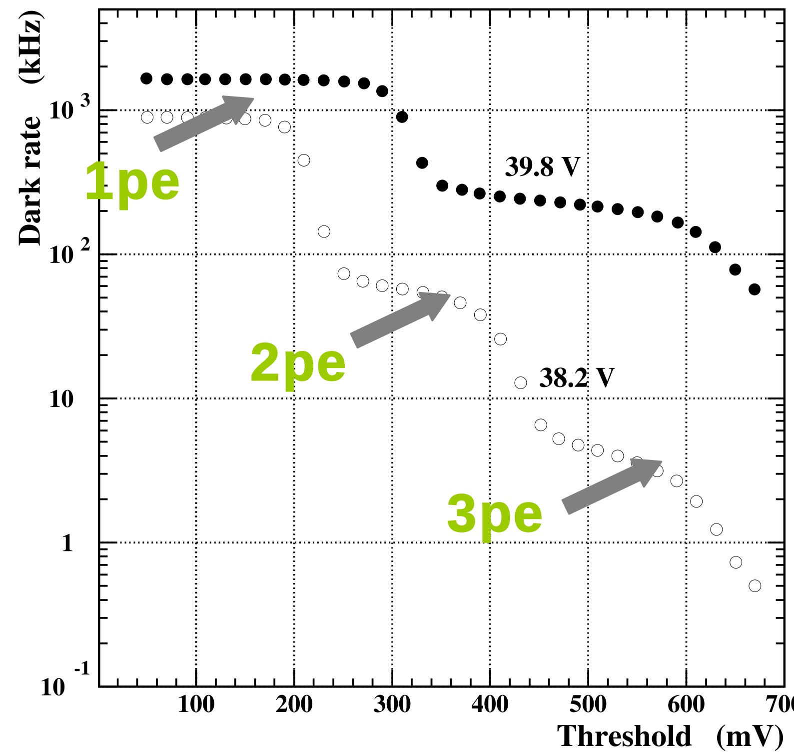
Photosensors

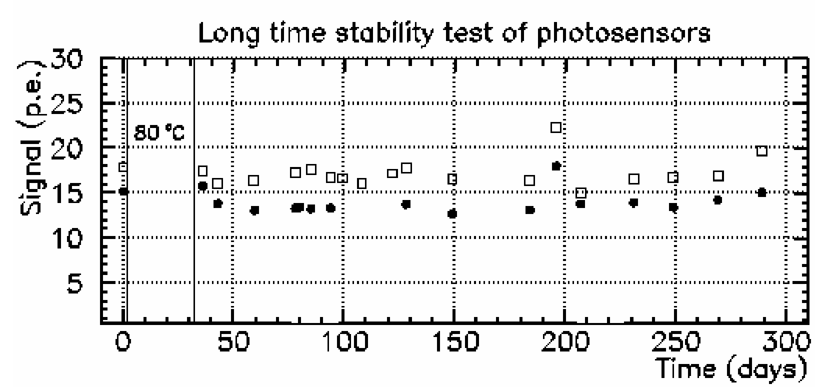
Absolute scale calibration using well separated p.e. peaks



MRS APD

Dark rate vs threshold





Heat test at 80°C

Summary + Outlook

- Overview of physics of T2K experiment
- Physics of near detector (ND280)
- Near detector design and technology
  - On-axis
  - Off-axis: various components

Schedule

Beam line construction started in April 2004	on schedule
Start of ND280m detectors manufacturing	winter 2006/2007
ND280 hall construction start	April 2007
UA1 magnet installation	May 2008
50 GeV MR commissioning	2008
Complete ND280 building	December 2008
Begin installation of ND280 detectors	January 2009
Neutrino beam line + ND280 commissioning	April 2009
T2K physics run	2009