Status of the long baseline T2K experiment

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Outline

- ν oscillations
- T2K:
  - off-axis
  - principles
  - detectors
  - physics sensitivity
  - plan

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
$\theta_{23} \approx 45^o$
$\Delta m^2_{23} \sim 2.5\times10^{-3}$ eV^2

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

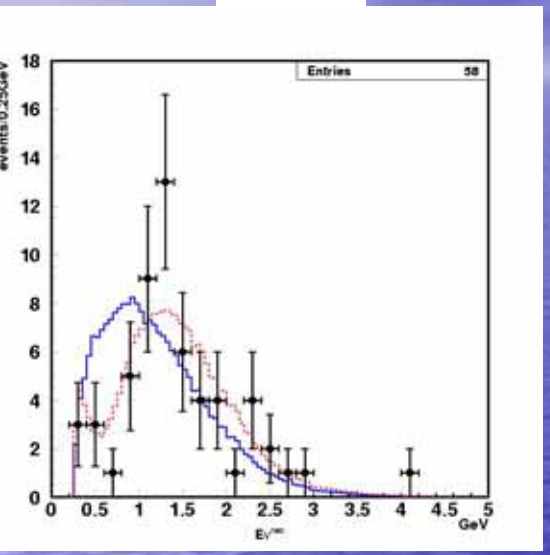
δ is unknown

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

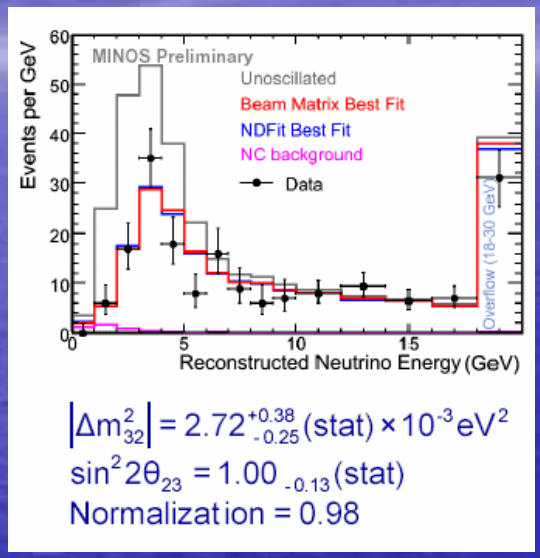
Mixing	Quarks	Leptons
1-2 θ_{12}	13^o	32^o
2-3 θ_{23}	2.3^o	45^o
1-3 θ_{13}	~ 0.5^o	<12^o

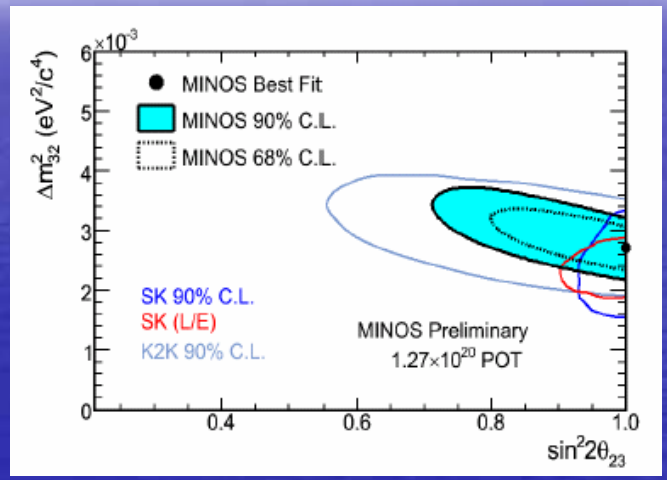
ν oscillations in accelerator experiments

K2K



MINOS





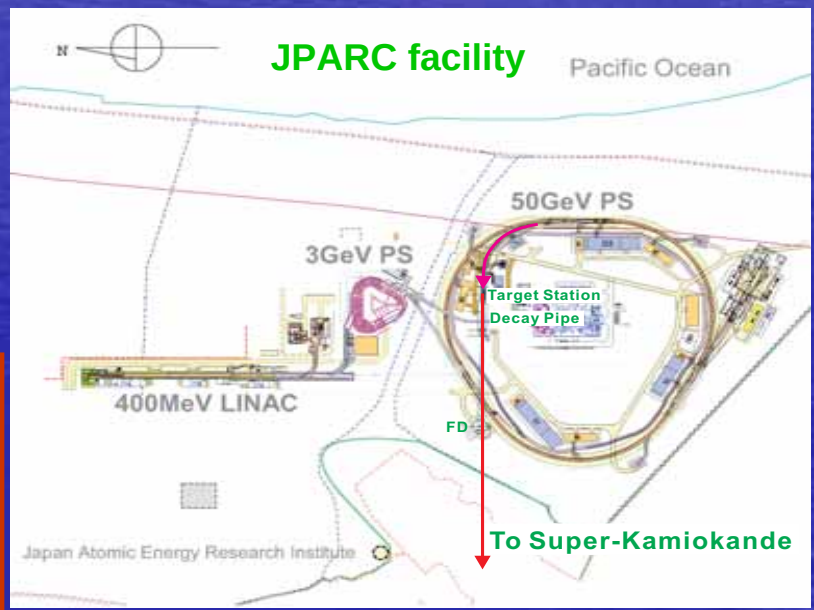
LBL accelerator experiments

precise measurement of mixing parameters
value of θ_{13}
CP violation in lepton sector
mass spectrum: normal or inverted

2nd generation: T2K, NOVA…

T2K (Tokai to Kamioka)

12 countries, ~60 institutions, ~300 collaborators

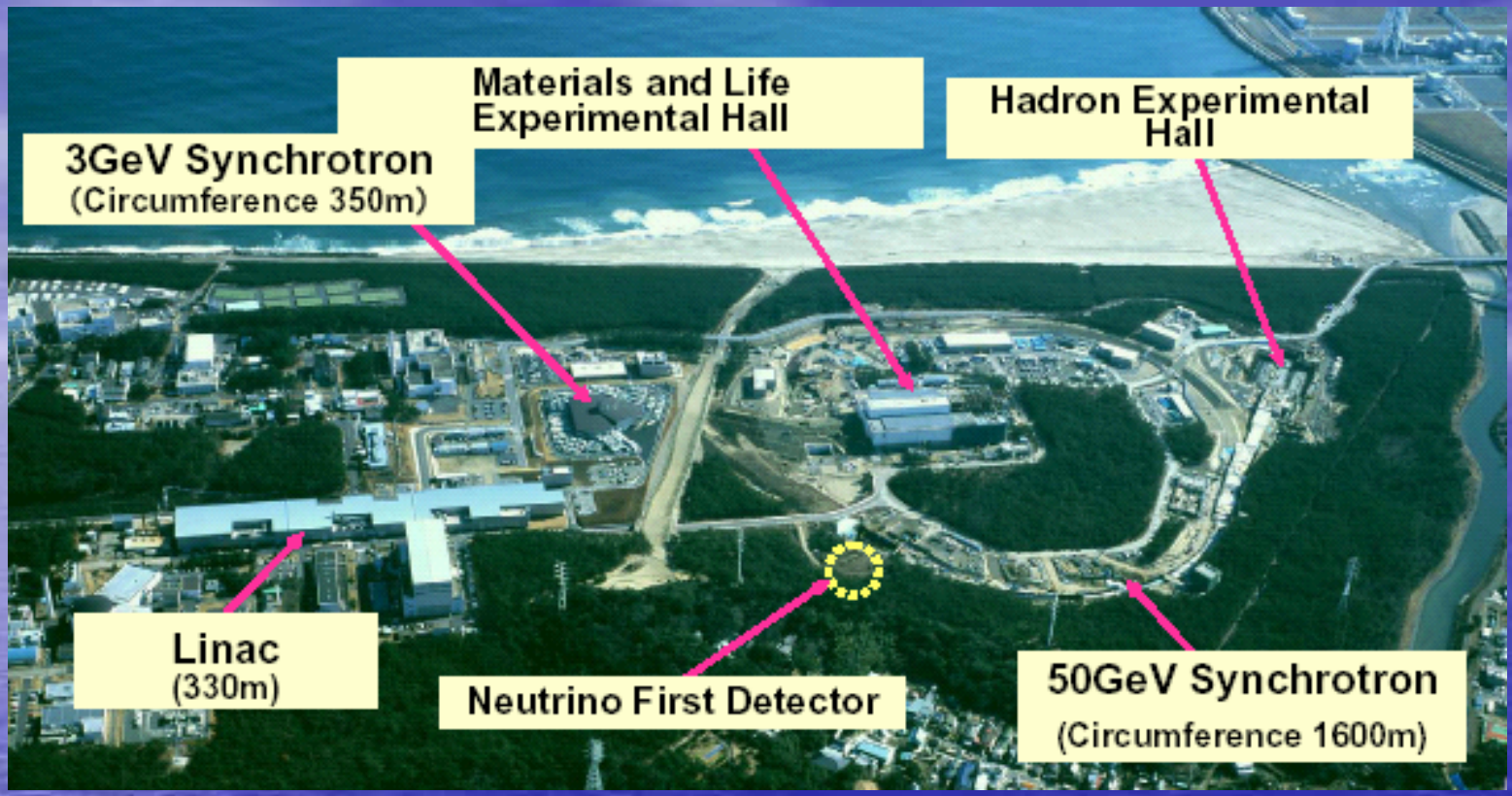


ν beam off-axis on-axis

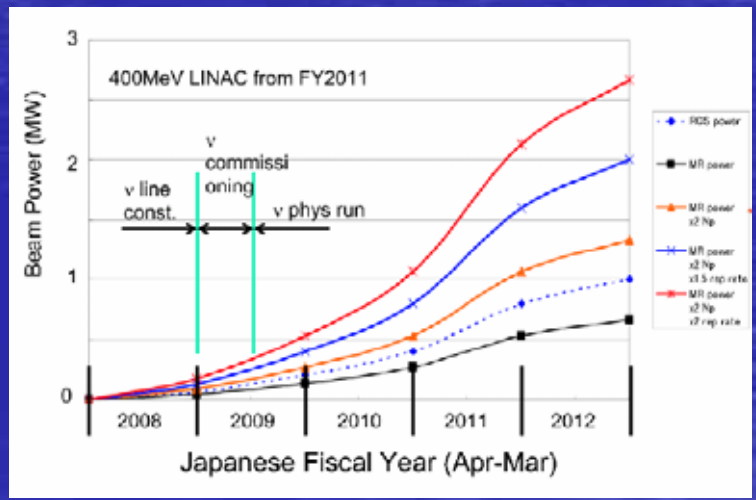
	JPARC	MINOS	Opera	K2K
E(GeV)	50	120	400	12
Int(10^{12}ppp)	330	40	24	6
Rate (Hz)	0.29	0.53	0.17	0.45
Power (MW)	0.77	0.41	0.5	0.0052

~1GeV ν_μ beam ($\times$100 of K2K)

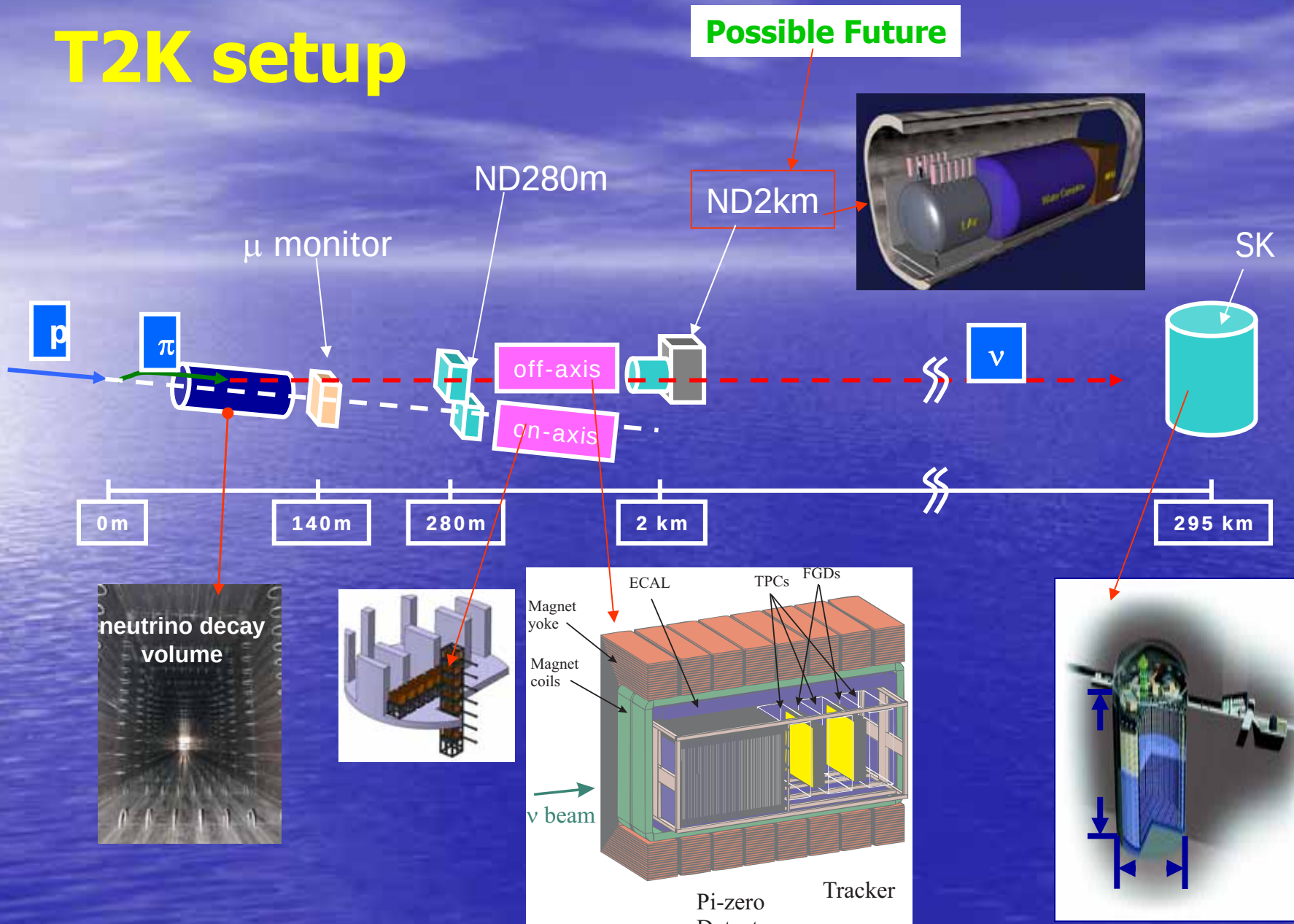
JPARC



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

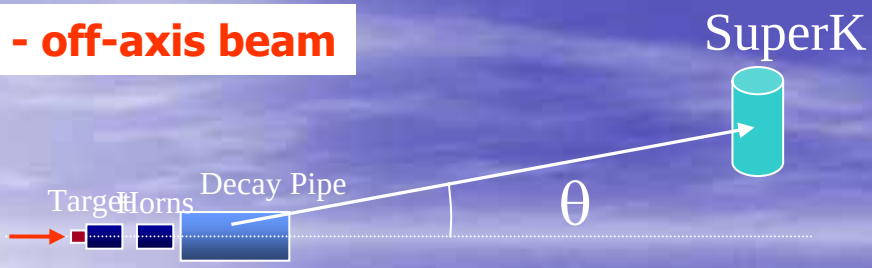


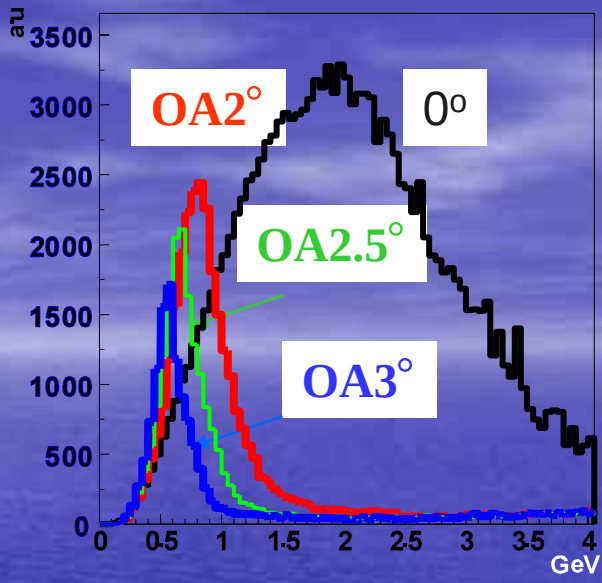
T2K setup


Possible Future
ND280m
ND2km
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

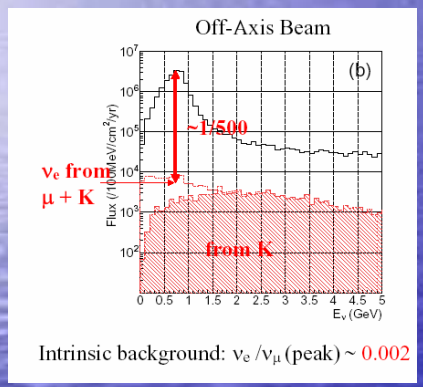
T2K principles

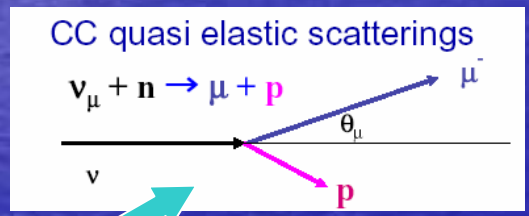
- off-axis beam



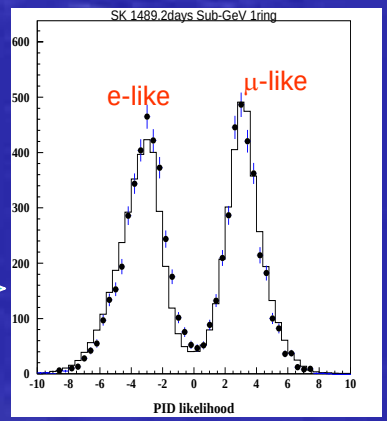


- small contamination of ν_e





- E_ν reconstruction using CCQE kinematics $\nu_\mu n \rightarrow \mu^- p$

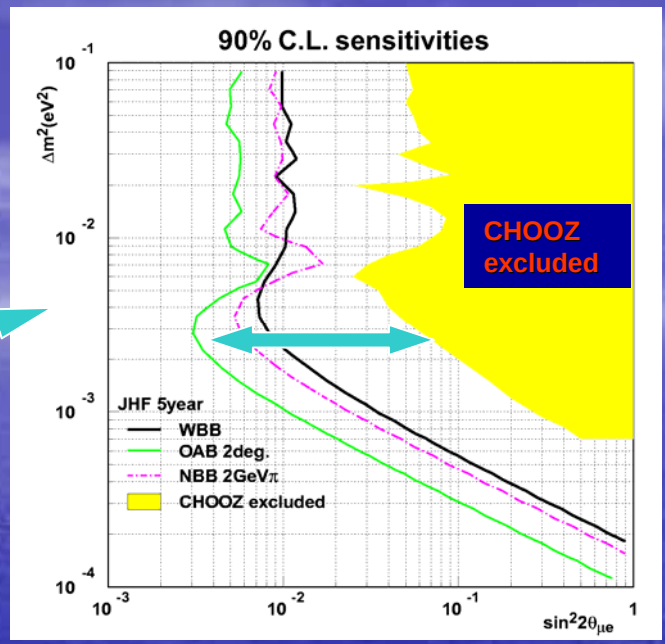


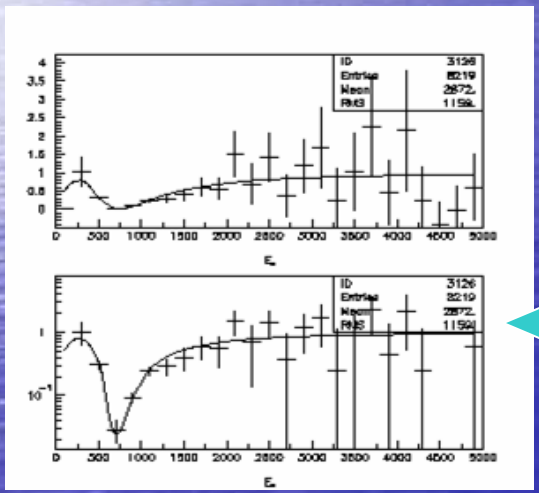
- PID at SK
  μ/e identification
  background suppression
  in ν_e search (K2K)

- ν spectrum at SuperK predicted by correction of ν spectrum at Near Detector (ND280m) by Far/Near ratio

Physics Goals

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





- Measurement of Δm^2_{23} with accuracy of 3% and mixing angle with accuracy of 1%
  $\delta(\sin^2 2\theta_{23}) \sim 0.01$
  $\delta(\Delta m^2_{23}) < 1 \times 10^{-4}$ eV^2

- Search for sterile components by NC events

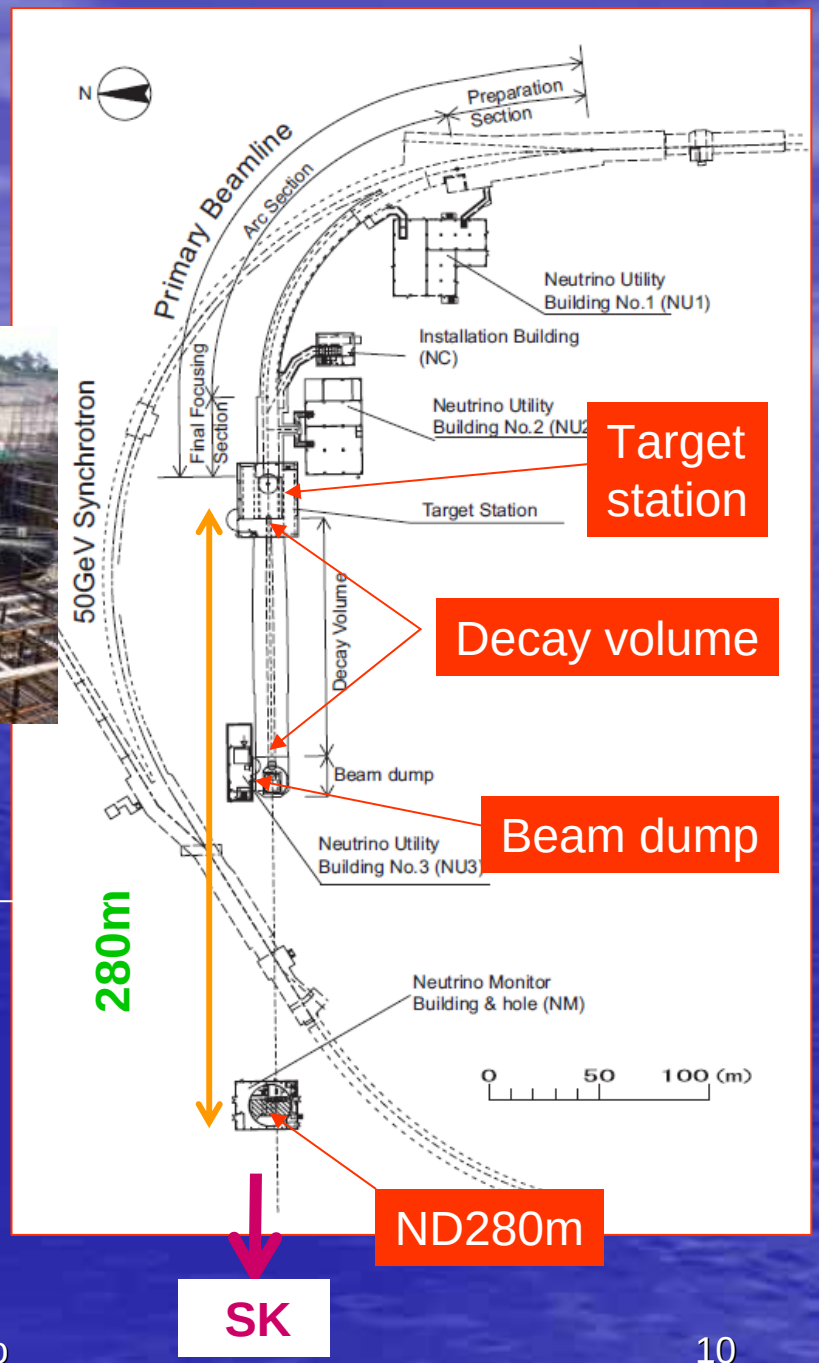
T2K beam line

Components

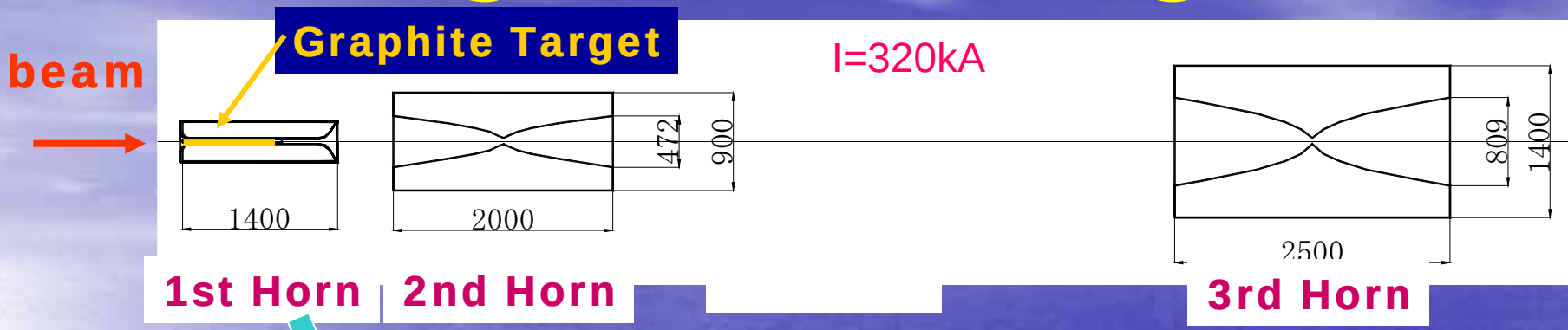
- Primary proton beam line
  - Normal conducting magnets
  - Superconducting arc
  - Proton beam monitors
- Target/Horn system
- Decay pipe
- Beam dump
- muon monitors
- Near neutrino detector (ND280m)

Special Features

- **Superconducting combined function magnets**
- **Off-axis beam**



Target and horn magnets



Graphite target Prototype
- thermal shock resistant to 0.75 MW
- He-gas cooling system

1st Horn excitation	May 2006
Operation at 320 kA	July 2006
Production of 1, 2, 3 Horns	2007
Installation	2008

Requirements for Near Detectors

Predictions of ν flux and interactions at Far Detector

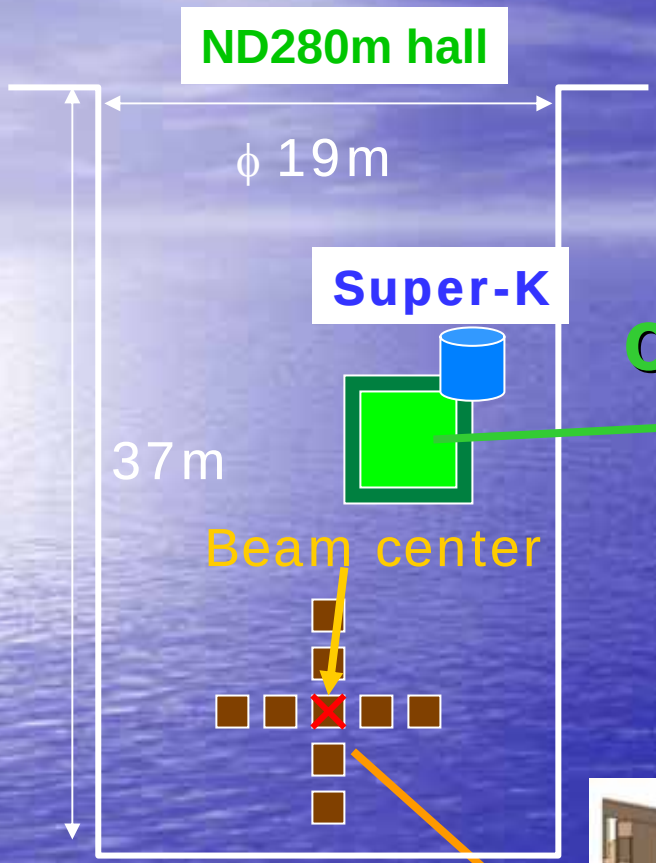
Profile of ν beam → determination of off-axis angle (on-axis detector)
ν_μ and ν_e fluxes, charged current processes (tracking detectors)
π^0 production cross sections (Pi-Zero, Ecal)

Neutrino spectrum at Far Detector is predicted by correction of neutrino spectrum at ND280 by Far/Near ratio

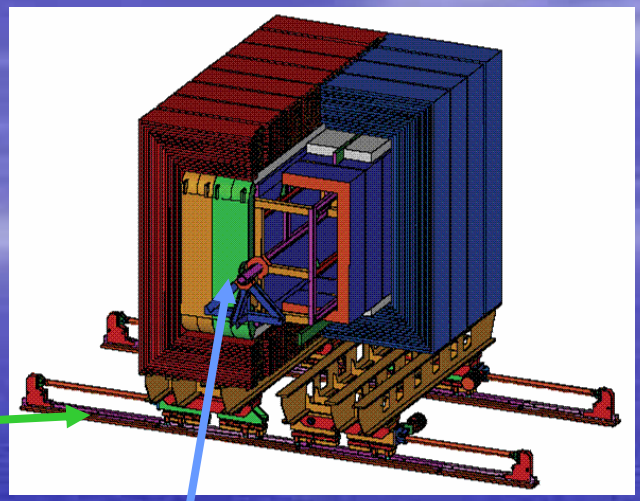
Neutrino flux measurement at ND280 with accuracy 5%

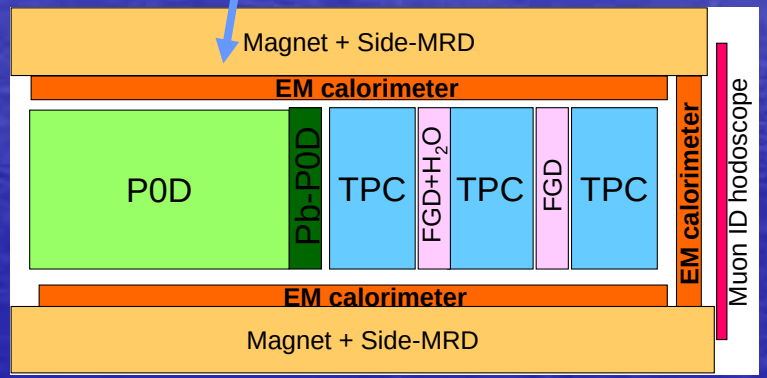
ν_μ n → μ^- p CCQE $E\mu \leq 1$GeV, $\theta_\mu = 0 – 180$ deg
Muon momentum scale uncertainty – 2%
Fermi motion → Muon momentum resolution – 10%
μ^+/μ^- identification
Detection of recoil protons
Charged pion measurement
Measurement of ν_e contamination with 10% uncertainty
Measurements of neutrino interactions in water target
Neutrino beam direction accuracy <<1 mrad

Near Detectors at 280 m

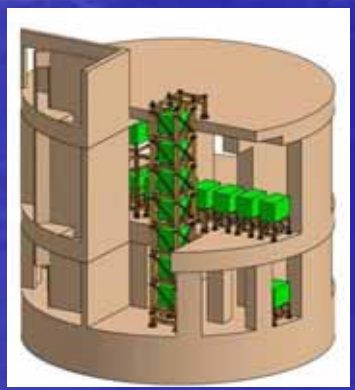


Off-axis (~2°)



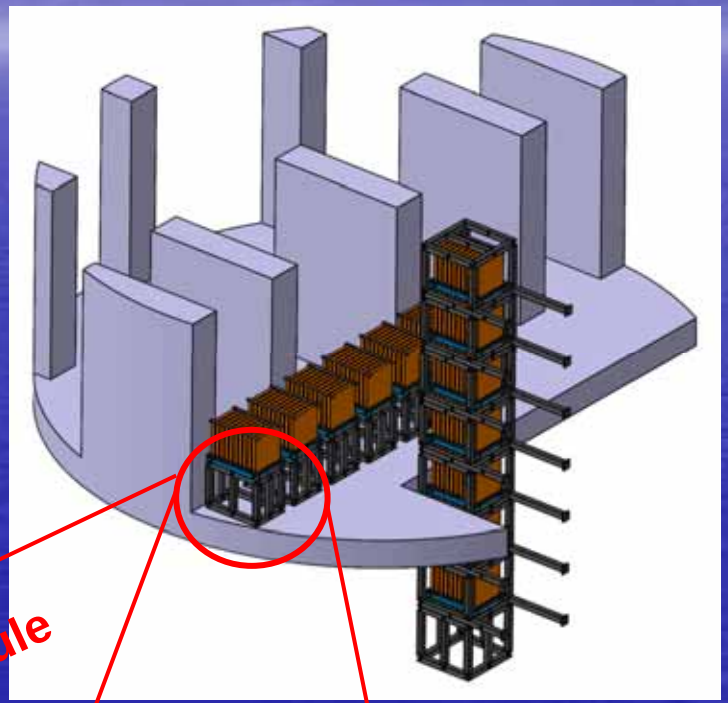


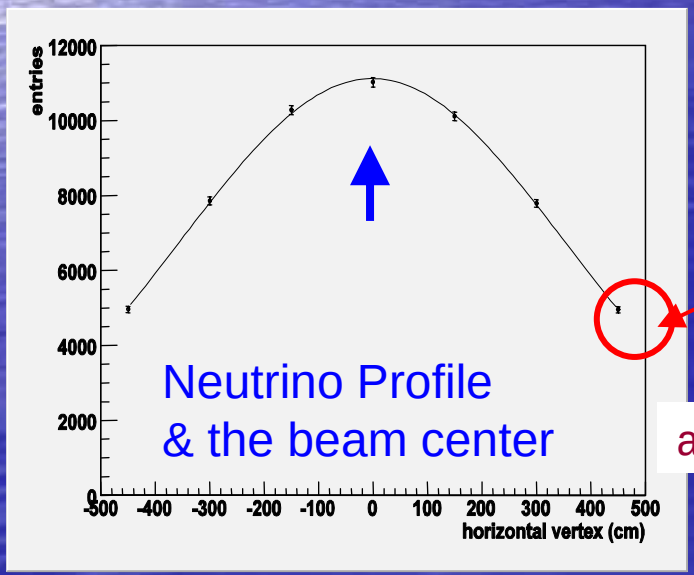
On-axis (0°)



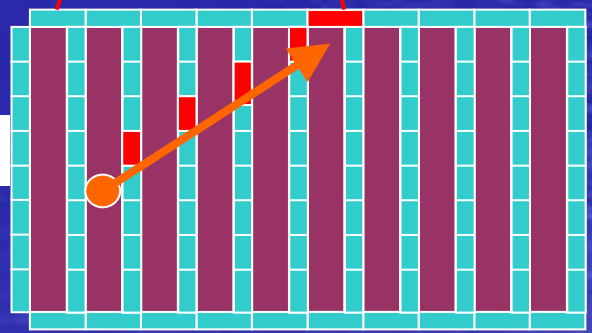
On-Axis Neutrino Monitor (INGRID)

- Monitor the neutrino beam
  - Direction
  - Profile
  - Intensity (& Energy)
- Iron-Scintillator sandwich detector
  - Extruded Scintillators
  - New Photo-Sensor (MPPC/MRS APD)





Event Rate/module

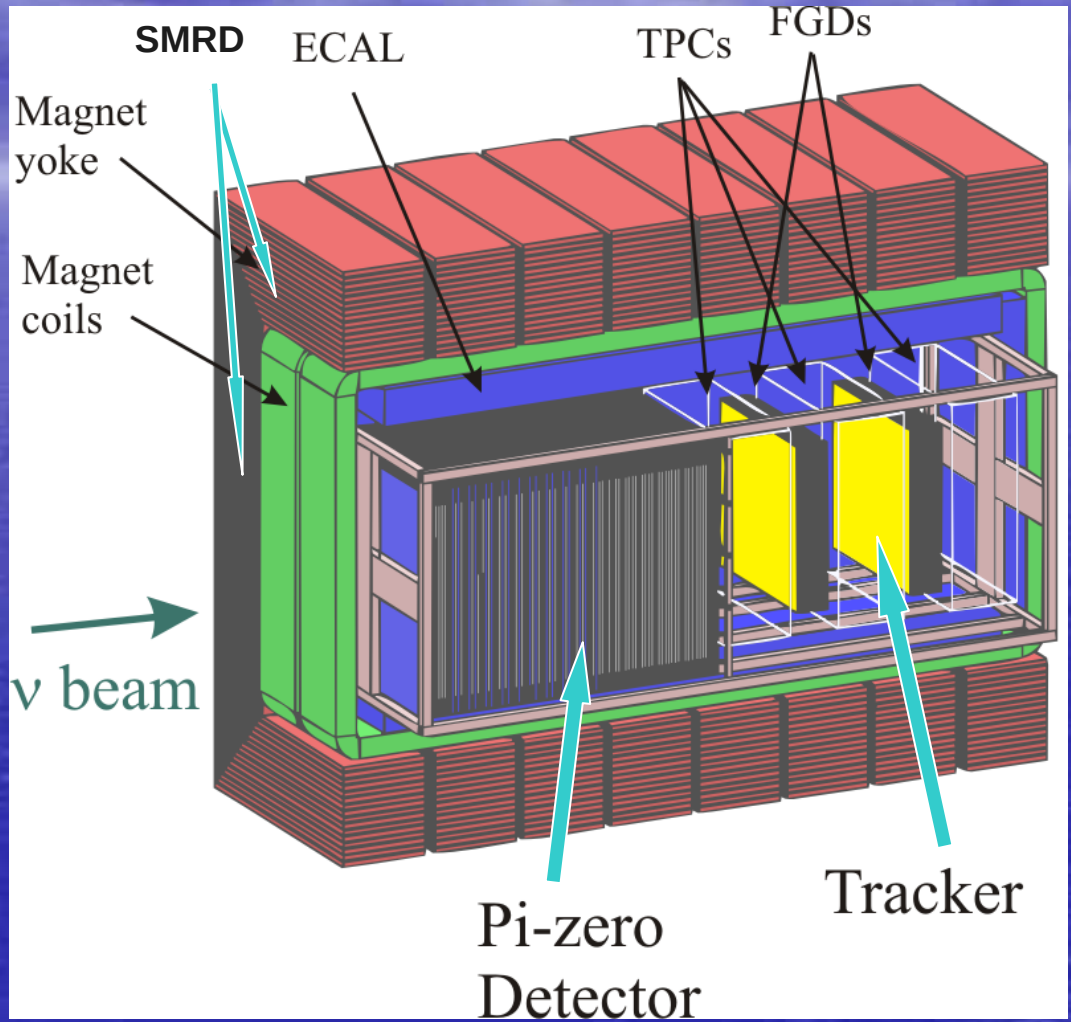


accuracy ~ 0.18 mrad

ND280m off-axis detector

Conceptual design

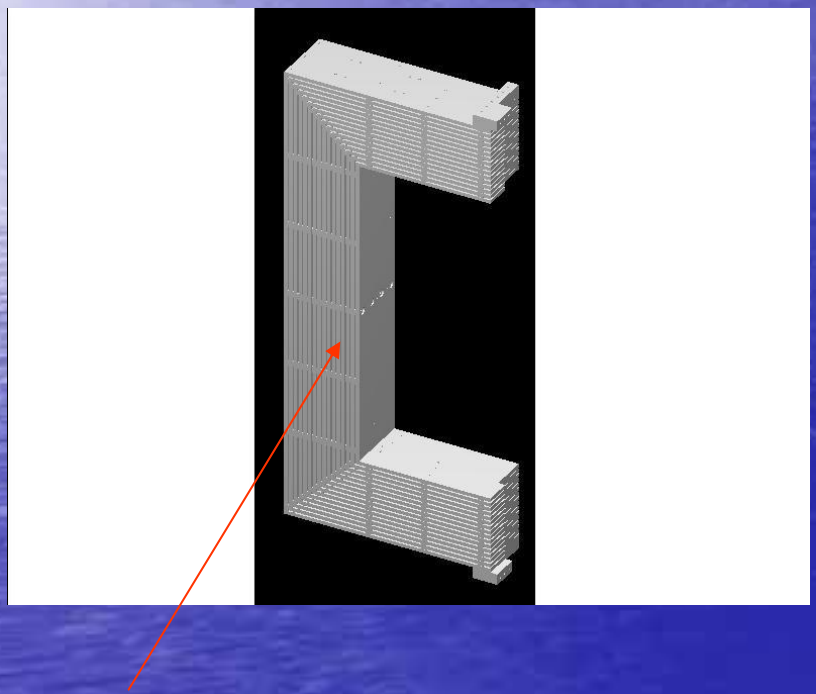
- UA1 magnet
  0.2 T
  inner volume:
  3.5×3.6×7.0 m^3
- Pi-Zero optimized for π^0 from NC
- Tracker optimized for CC studies
- surrounded by ECAL and Side Muon Range Detector



UA1/NOMAD magnet

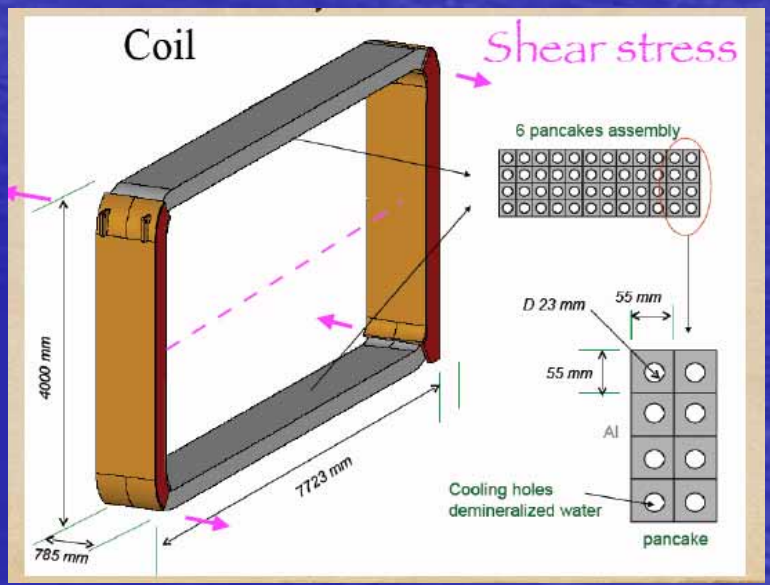
Work at CERN:
Sandblasting/Polishing
Painting
Measurements for SMRD installation
Support system
Preparation for transportation to Japan

16 C-shape yokes



Instrumented with scintillators

4 coils

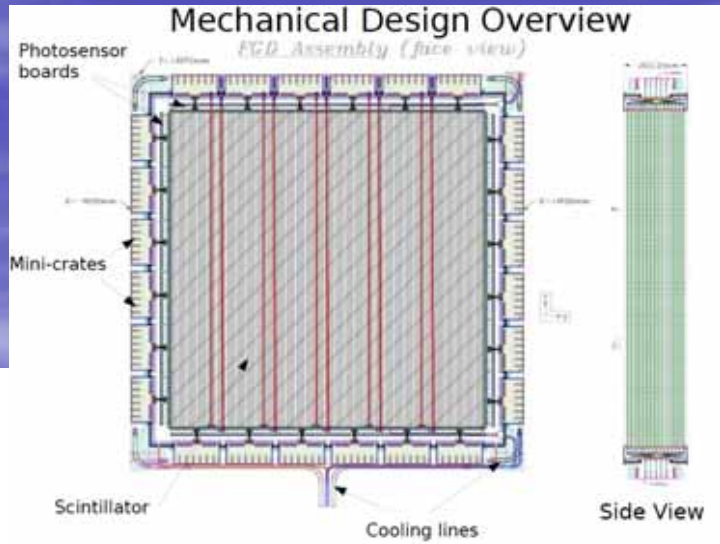


FGD

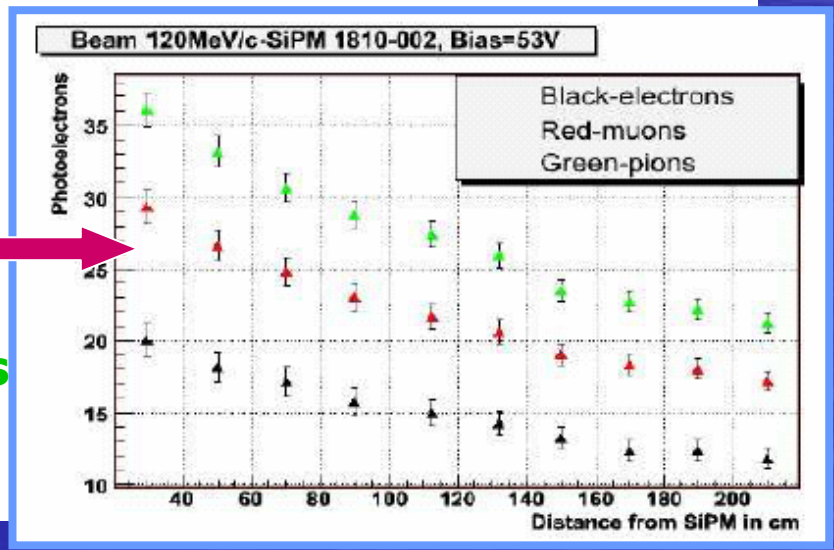
Two FGD's

1st: x-y layers of scintillators

2nd: water rich detector



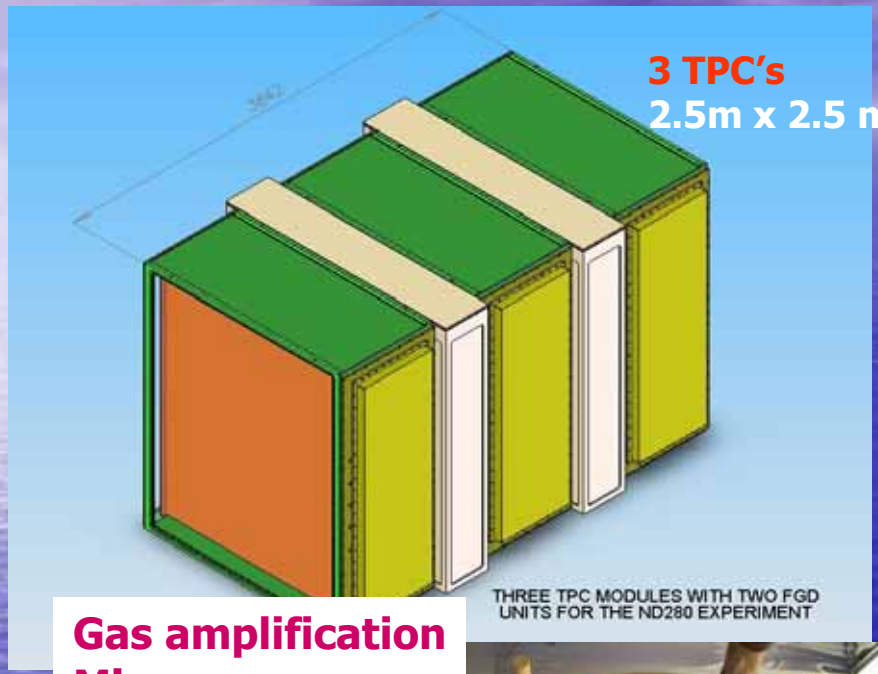
Size of FGD ~ 2.3 m x 2.4 m x 36 cm
with 1cm x 1cm scintillator bars
Total weight 1.2 ton / FGD
Thickness 0.36 m
to make particles get out of FGD into TPC, especially for pions, to measure their momentum before interacting with materials
Cell size 1 cm
lower particle detection threshold for protons down to 200 MeV/c
Readout WLS fiber Y11, one end by multi-pixel Si APD's
Back FGD 3 cm passive water layers between each x-y sci. planes
Future upgrade water-based scintillator

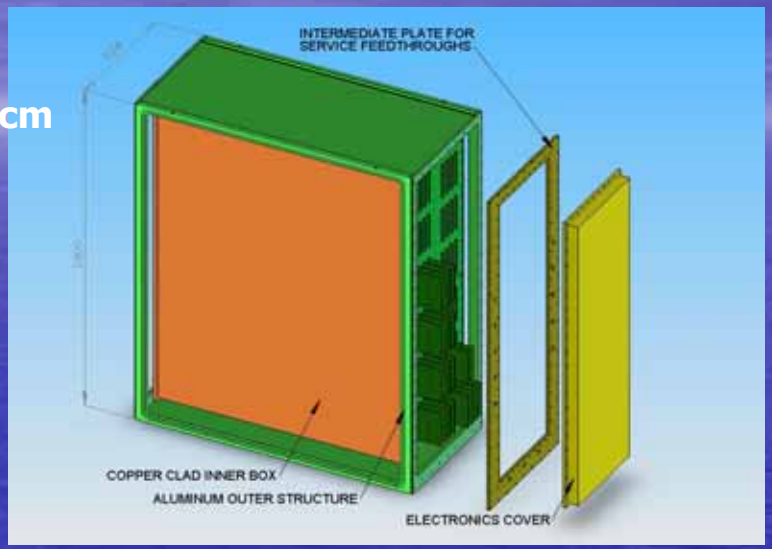


ND280m tracker

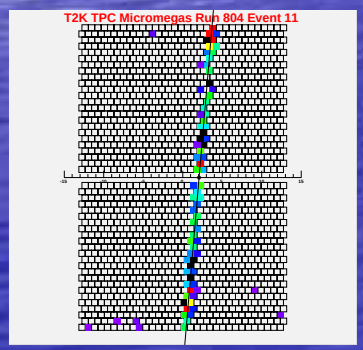
solid active (+ water) target modules (FGD)
gas time projection chamber modules (TPC)

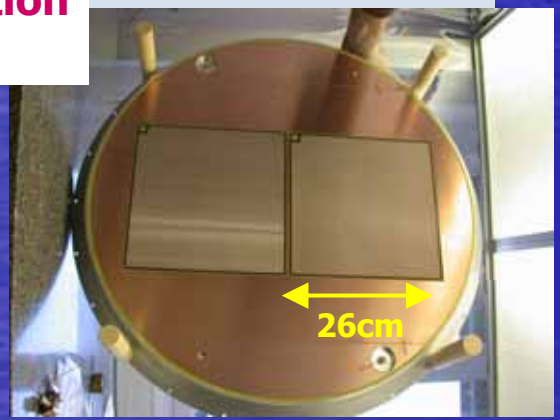
Requirements :
σ(p)/p < 10 % at 1 GeV/c
dE/dx capability: separate e from μ





Gas amplification
Micromegas





- **6 read-out planes (0.7x2.0 m²)**
- **Maximum drift distance 1.0 m**
- **B=0.2 T E=200V/cm**
- **Pad size: 0.6 to 0.8 cm**
- **~100k channels**

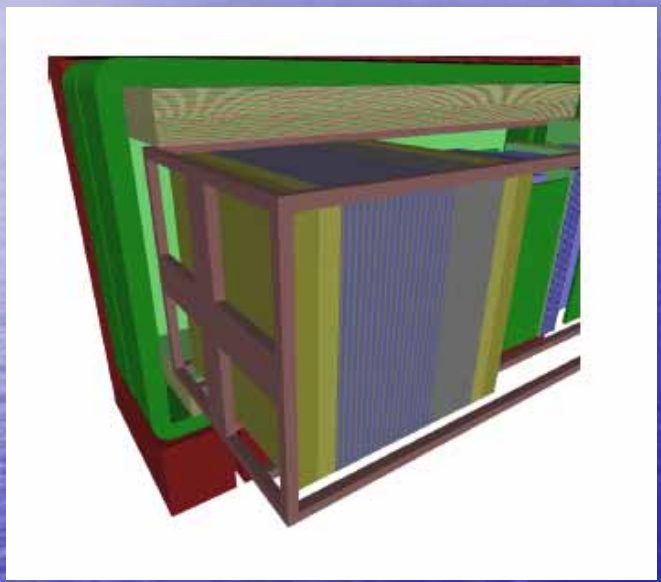
Prototype test:
σ(p)/p ~ 8 % at 1 GeV/c
for 70 cm track
dE/dx ~ 12% for 34 cm track

Pi-Zero Detector (POD)

NC π^0 measurement
ν_e contamination

Total mass ~15 t
Fiducial ~5 t
H_20 target ~1.7 t

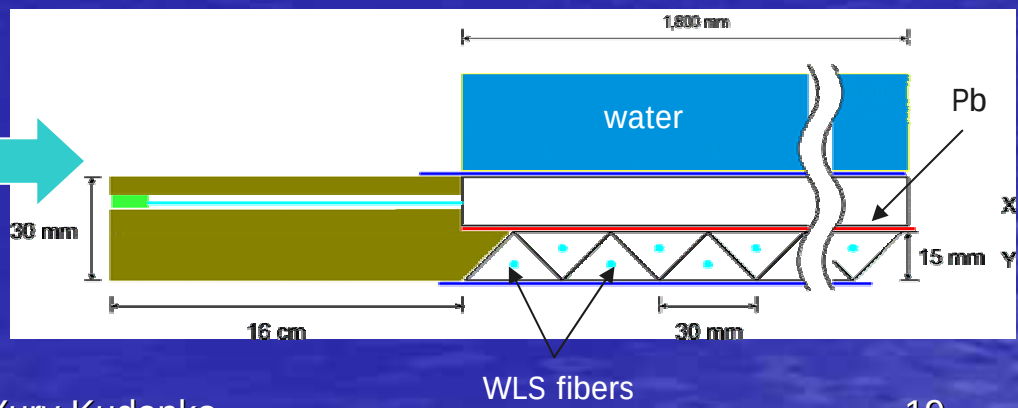
1.7 x 10^4 NC single π^0 events in water target for 10^{21} POT



Approx volume 2 x 2 x 2.4 m^3

Expected parameters:
σ_E ~ 5%/√E +10%
efficiency for π0 reconstruction 50-60%

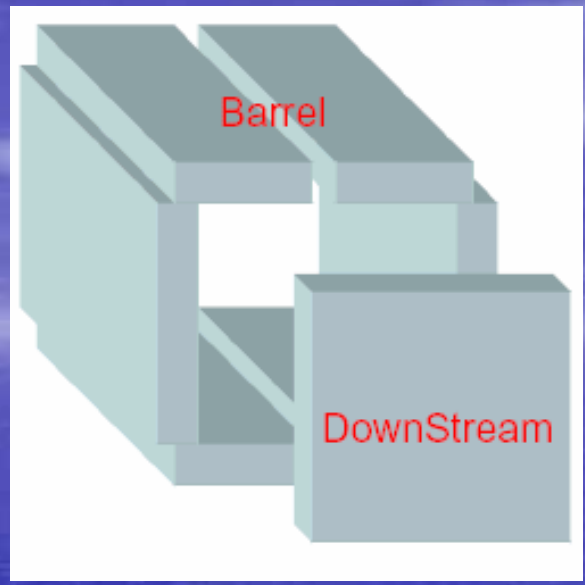
POD layer:
- **co-extruded triangular polystyrene bars with TiO2 reflective layer**
- **central hole with WLS fiber**
- **thin (0.6 mm) lead sheets**



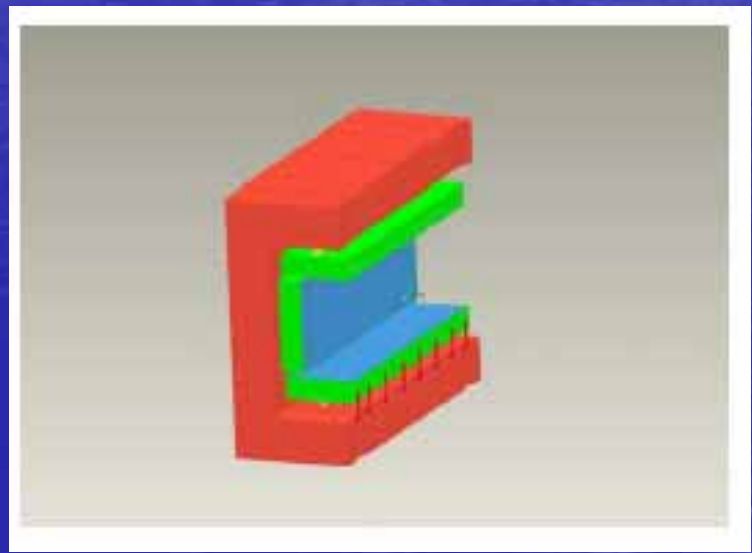
ECAL

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
  - multi-pixel Si APD's, ~20k devices



SMRD

Magnet yoke: 17 mm air gaps between iron plates
SMRD: 6 layers of the gaps instrumented with scintillator slabs
about 4000 slabs
S-type configuration for fiber readout
both-end readout using multi-pixel Si APD's

Sci Slab:
Length = ~ 87 cm
Width = ~ 18 cm
Thickmess = 10 mm

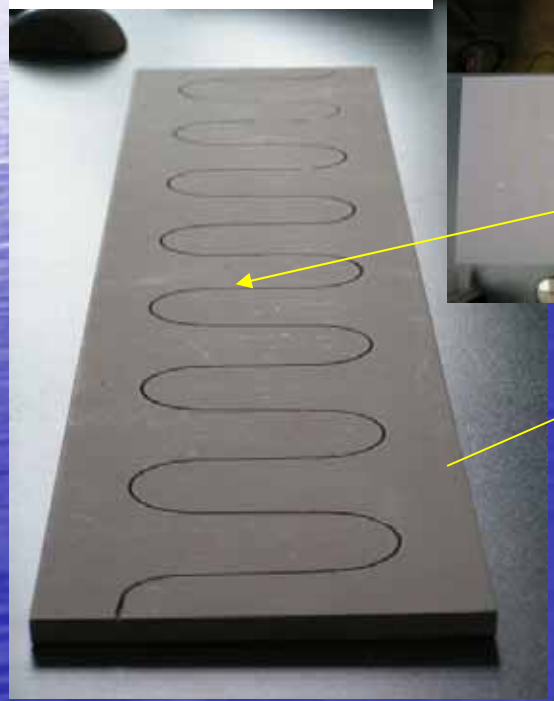
S-shape grooves
Depth 4 mm
Length ~ 2.5 m

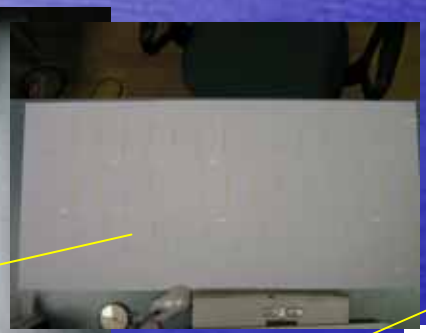
Y11, double clad,
1 mm diameter

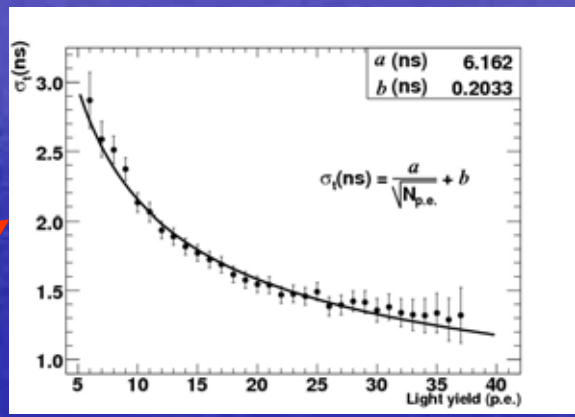
Beam test with 1.4 GeV/c pions

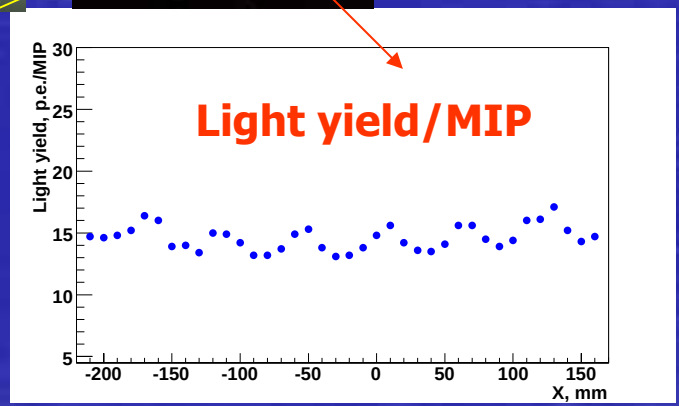
Light yield	15-20 p.e.
Timing (σ_t)	1.5 – 2.0 ns
space resolution	10-11 cm
efficiency (MIP)	> 99%

time resolution





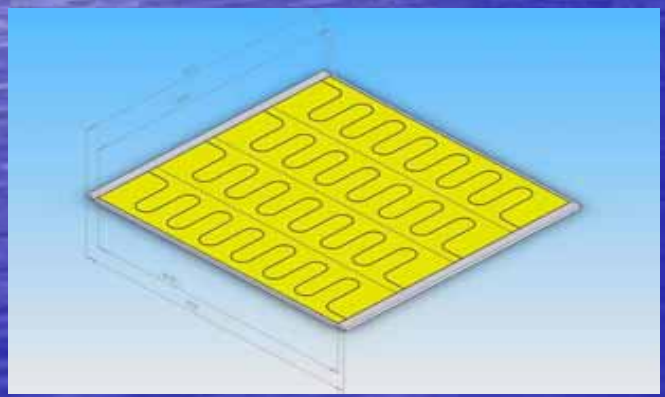




SMRD/INGRID/Ecal Modules

Uniplast, Vladimir

Extruded plastic scintillators



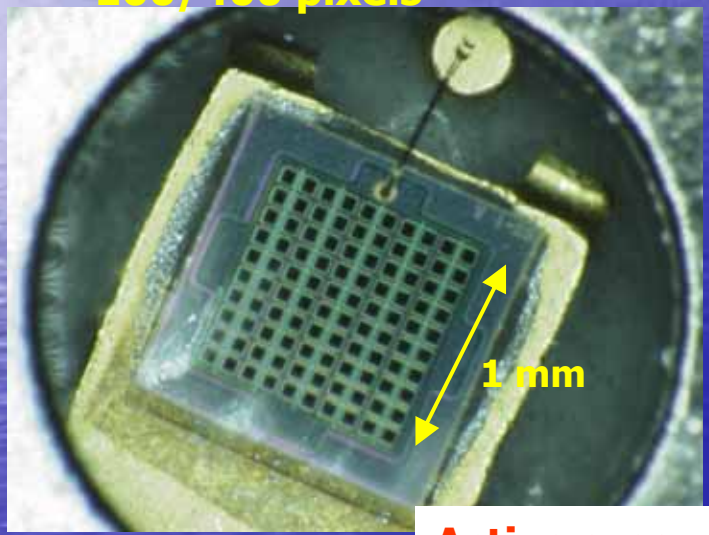
Photosensors

ND280m: ~ a few 10^5 m WLS fibers
individual fiber readout
magnetic field and limited space

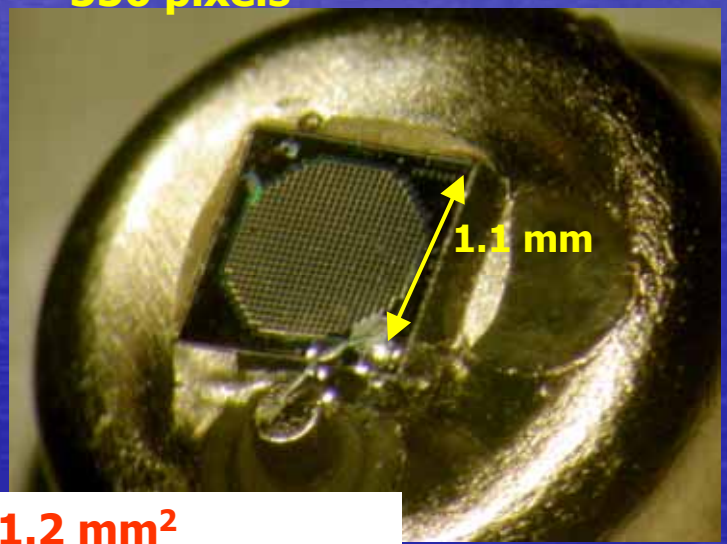
→ **> 10^5 photosensors**

Compact multi-pixel Si APD's operating in limited Geiger mode

MPPC (Hamamatsu,Japan)
100/400 pixels



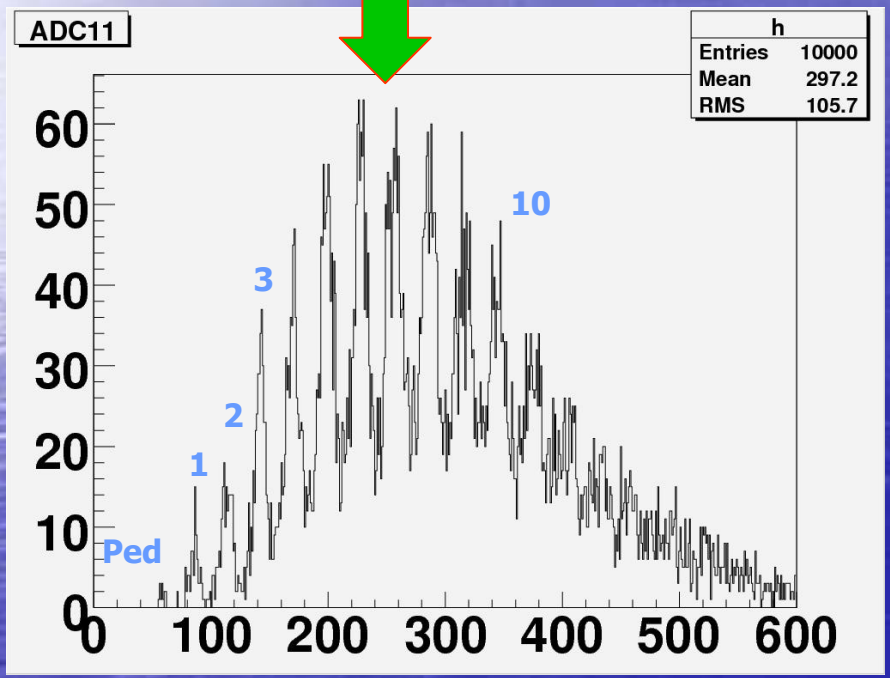
MRS APD (CPTA, Moscow)
556 pixels



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.)

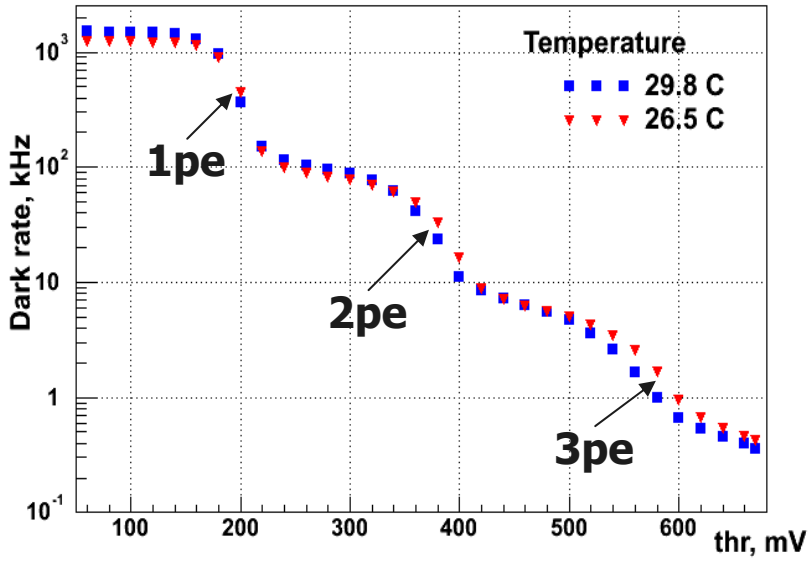
Photosensors

Absolute scale calibration using well separated p.e. peaks

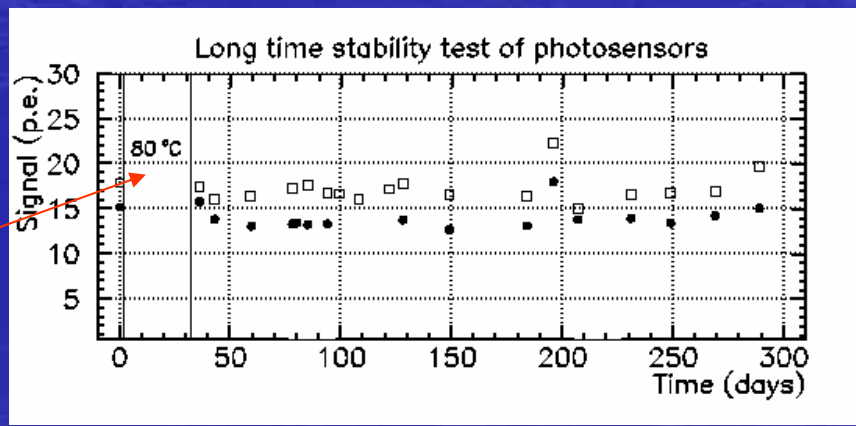


Dark rate vs threshold

MRS APD



Heat test at 80°C

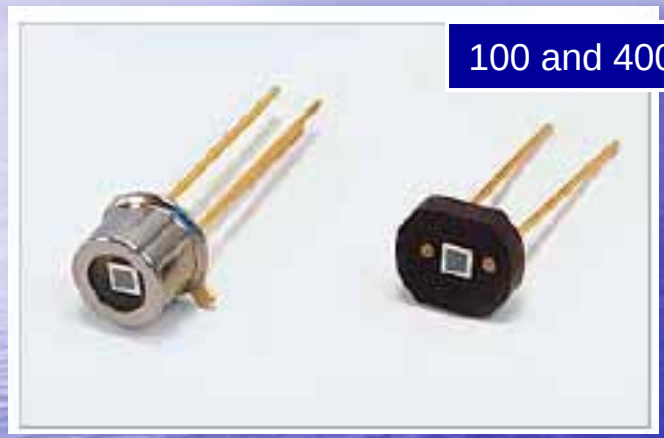


Photosensors

New compact packages

MPPC (Hamamatsu)

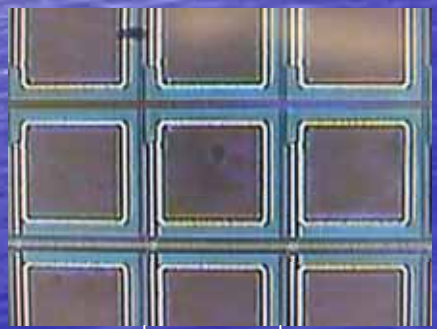
100 and 400 pixels



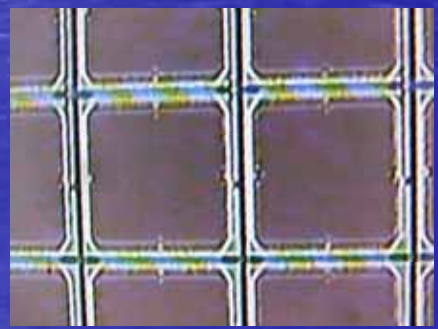
MRS APD (CPTA, Moscow)

556 pixels

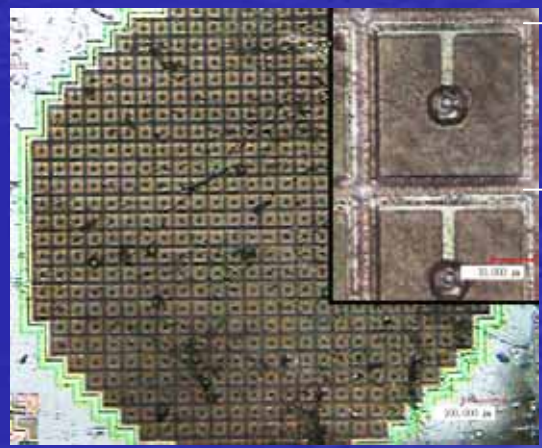
Microstructure of 100 pixel device



100 μm



new design



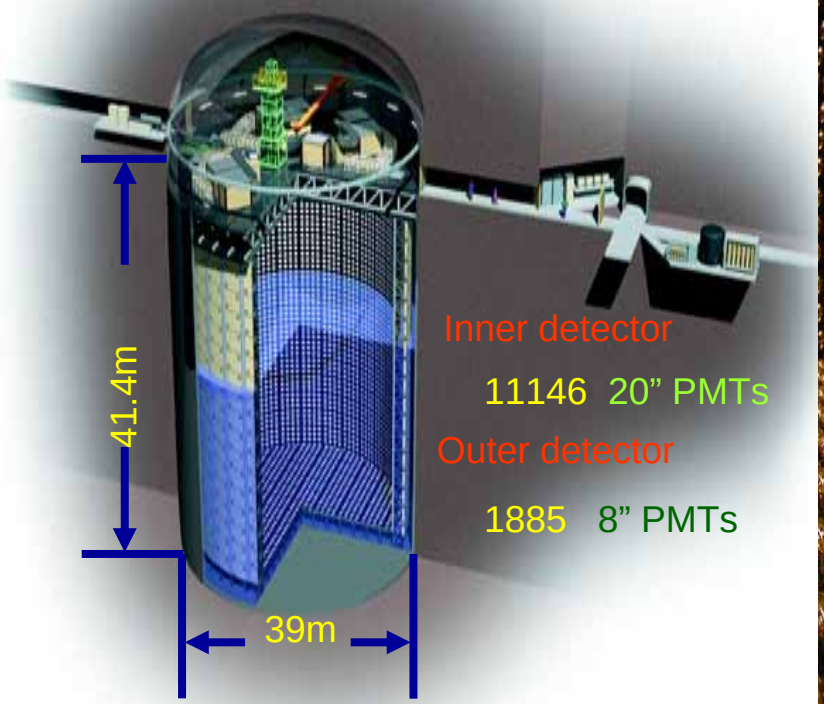
40 μm

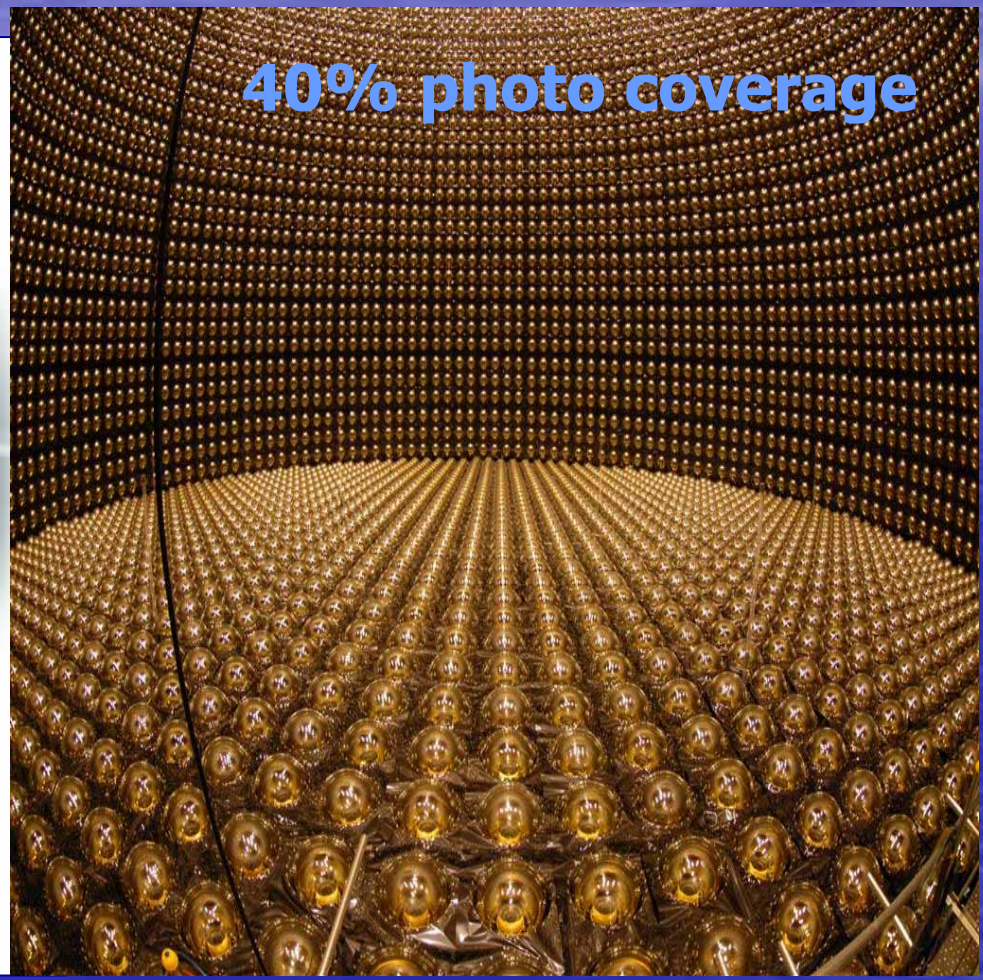
Far Detector SK-III

Super-Kamiokande III

Reconstruction is completed in April 2006

Total weight	50 kt
Fiducial	22.5 kt



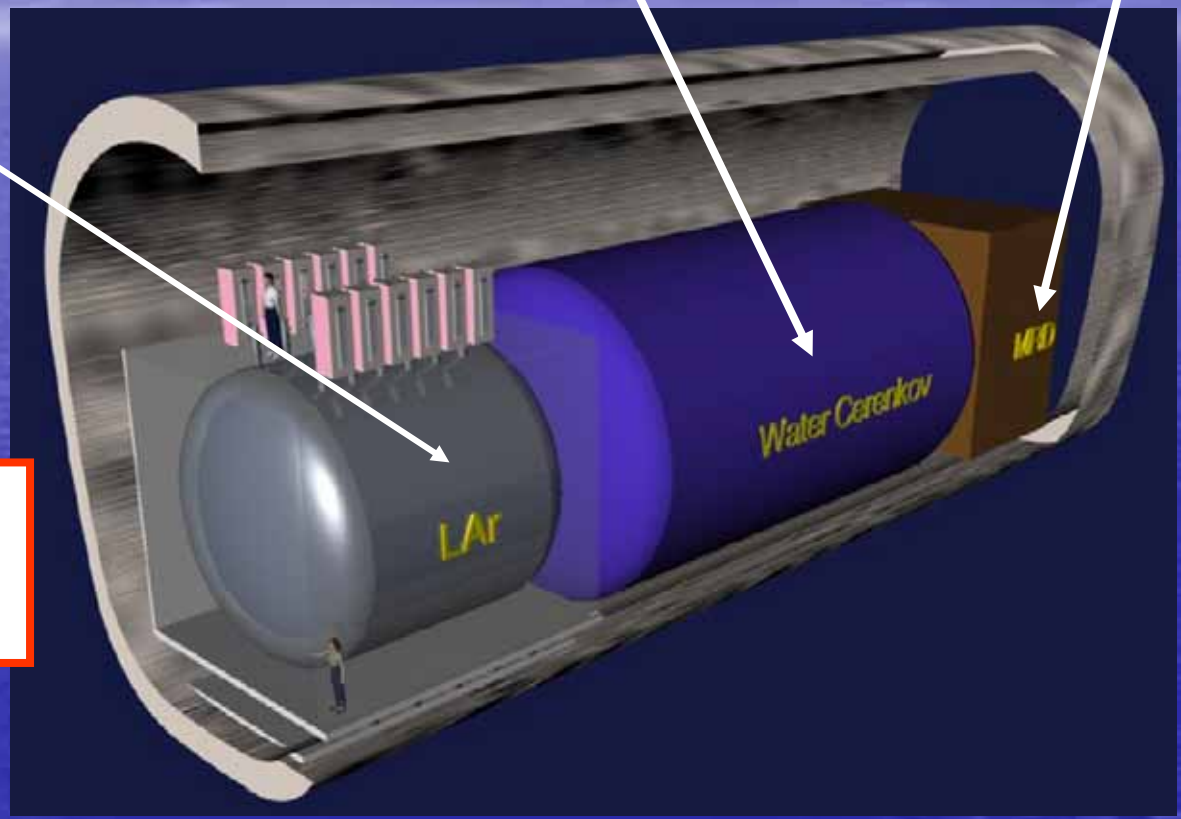


Detector at 2 km

Liquid Argon Detector
exclusive final states
frozen water target

Water Cherenkov Detector
Same detector target/technology as SK
~ 1 interaction/spill/1kton

Muon Ranger
Measure high energy tail of neutrino spectrum

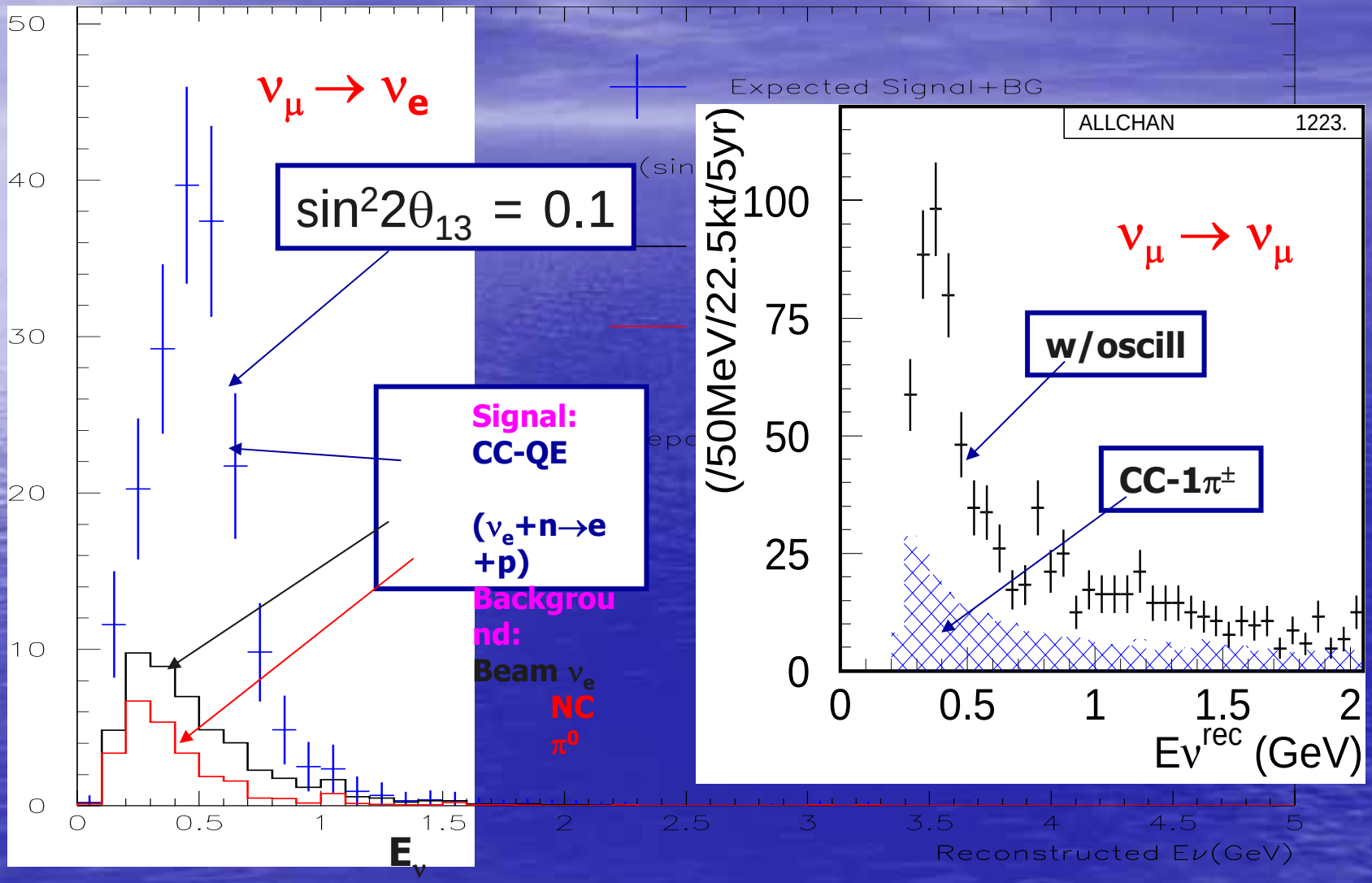


ν spectrum at 2 km similar to ν spectrum at SK without oscillations

smaller uncertainties of Far/Near ratio

possible future extension of the T2K complex

5 x 10^{21} POT ~ 5 years



Sensitivity ν_e appearance

5×10^{21} POT $\Delta m^2_{23}=2.5\times10^{-3}$ $\sin^2 2\theta_{23}=1$ $\sin^2 2\theta_{13}=0.1$

	ν_μCC BG	ν_μNC BG	beam ν_e BG	ν_eCC signal
Fully-contained, $E_{vis} \geq 100$MeV	2215	847	184	243
1 ring e-like, no decay-e	12	156	71	187
$0.35 \leq E_\nu^{rec.} \leq 0.85$GeV	1.8	47	21	146
e/π^0 separations	0.7	9	13	103

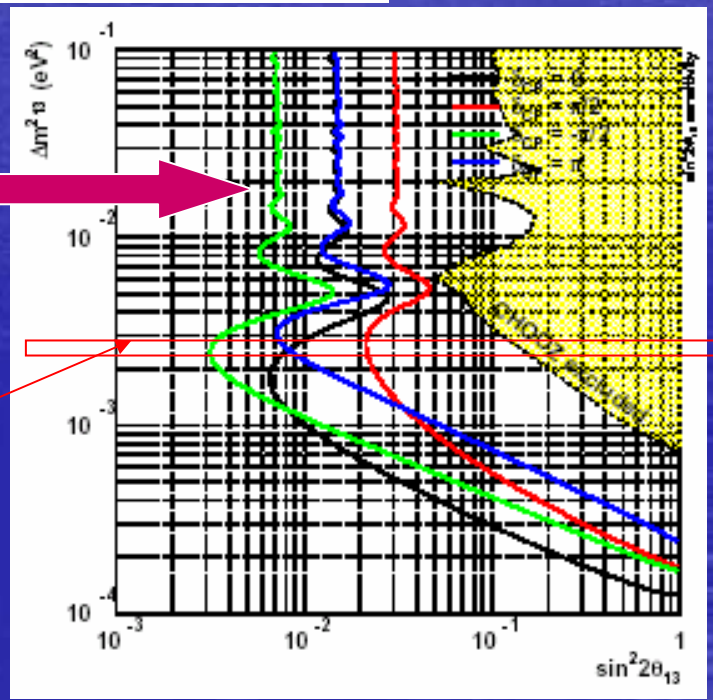
Background uncertainty 10%

$\delta_{CP} = 0$

$\delta_{CP} = \pi/2$

$\delta_{CP} = -\pi/2$

$\delta_{CP} = \pi$



$\Delta m^2_{23} = 2.5 \times 10^{-3}$

Sensitivity ν_μ disappearance

Fiducial volume fully-contained, μ-like, E_{vis}>30 MeV events at SK for 5×10^{21} POT

Δm^2 (eV^2)	CC-QE	CC-nonQE	NC	All ν_μ
No oscillation	3,620	1,089	96	4,805
2.0×10^{-3}	933	607	96	1,636
2.3×10^{-3}	723	525	96	1,344
2.7×10^{-3}	681	446	96	1,223
3.0×10^{-3}	800	414	96	1,310

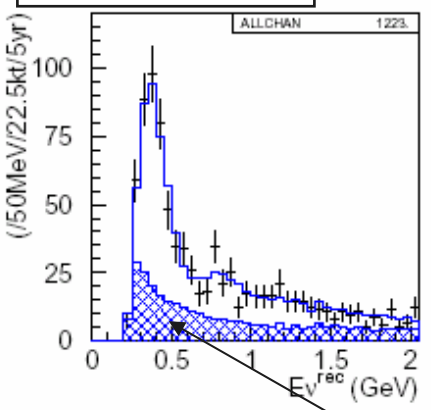
Requirements for systematics

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

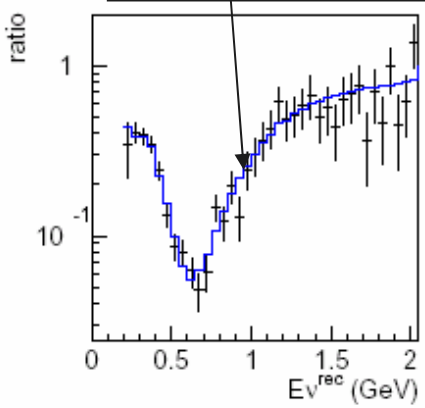
$\sin^2\theta_{23}=1$ $\Delta m^2_{23}=2.7\times10^{-3}$ eV^2

Stat errors

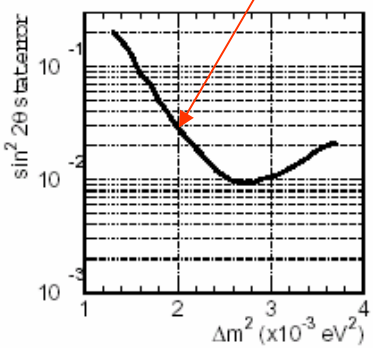
E_ν spectrum

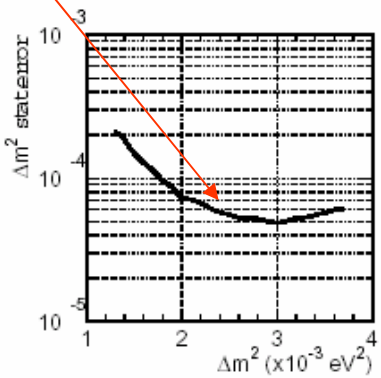


oscill/(w/oscill)



Non-QE





T2K schedule

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

Summary

T2K: second generation long baseline experiment
capitalizes on experience of SuperK and K2K

Main features: off-axis intensive ν_μ beam from JPARC,
SuperK and Near Detector Complex

Main goals: search for $\nu_\mu \rightarrow \nu_e$ and measurement of θ_{13}
precise measurement of Δm^2_{23} and θ_{23}

Neutrino beam is scheduled to start on 1st April 2009