Ускорительные нейтринные эксперименты: последние новости

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Mixing matrix

Pontecorvo-Maki-Nakagawa-Sakata matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = U \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

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

Oscillation experiments ⇒ Δm^2_{12} Δm^2_{13} $\sin\theta_{12}$ $\sin\theta_{23}$ $\sin\theta_{13}$

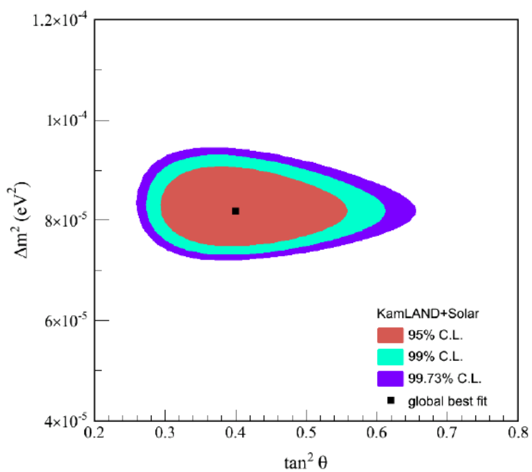
δ - CP violating phase

Neutrino mass and mixings

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

$\theta_{12}, \Delta m_{12}^2$

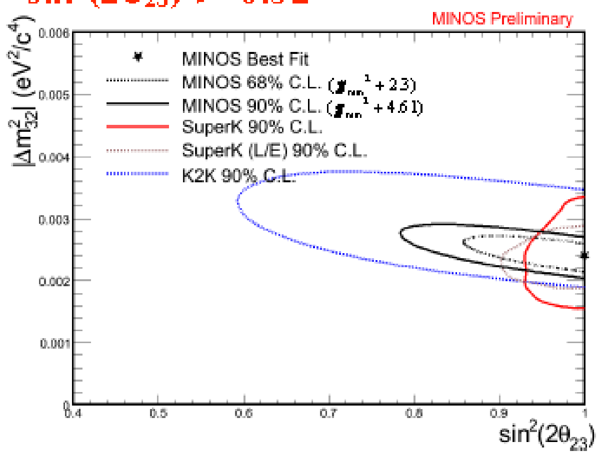
$\Delta m^2_{solar} = 8 \times 10^{-5}$ eV^2
$\sin^2(2\theta_{12}) = 0.86$



Solar + KamLAND

$\theta_{23}, \Delta m_{32}^2$

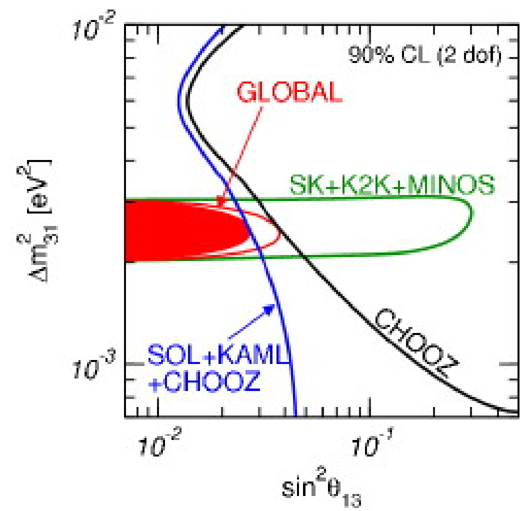
$\Delta m^2_{atm} = (2.2\sim2.6) \times 10^{-3}$ eV^2
$\sin^2(2\theta_{23}) > 0.92$



SK + K2K + MINOS

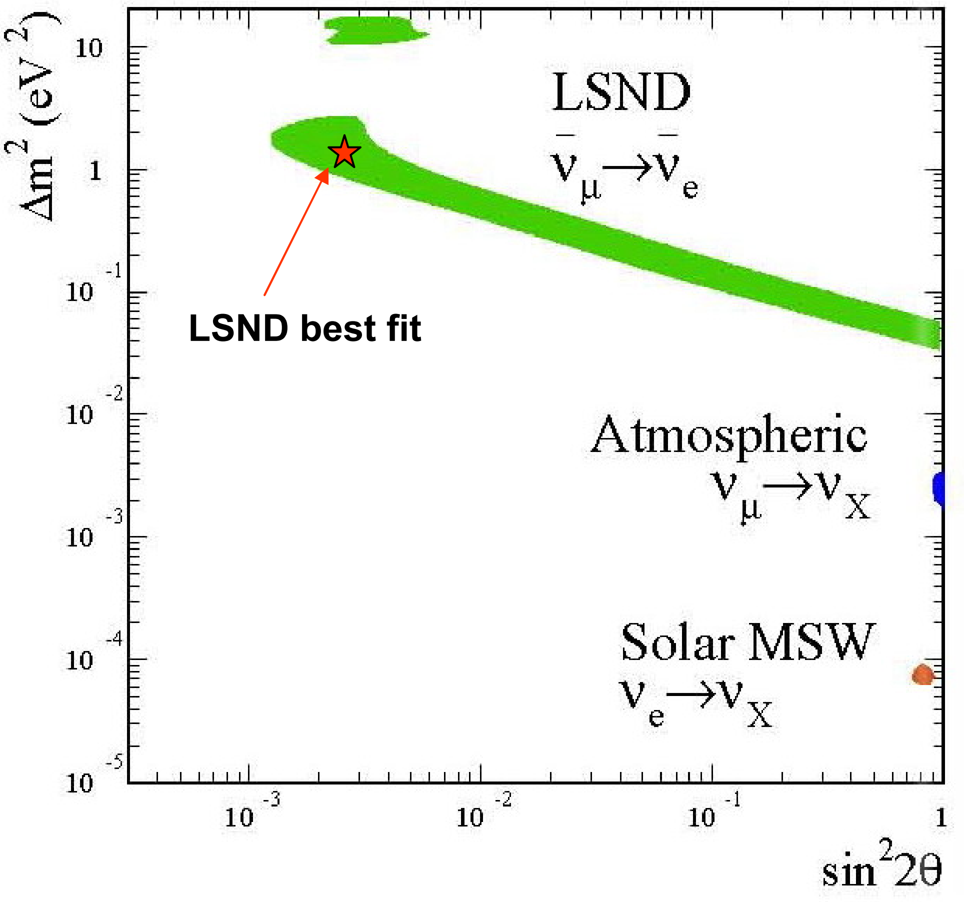
$\theta_{13}, \Delta m_{31}^2$

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



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

Oscillations before first MiniBooNe result



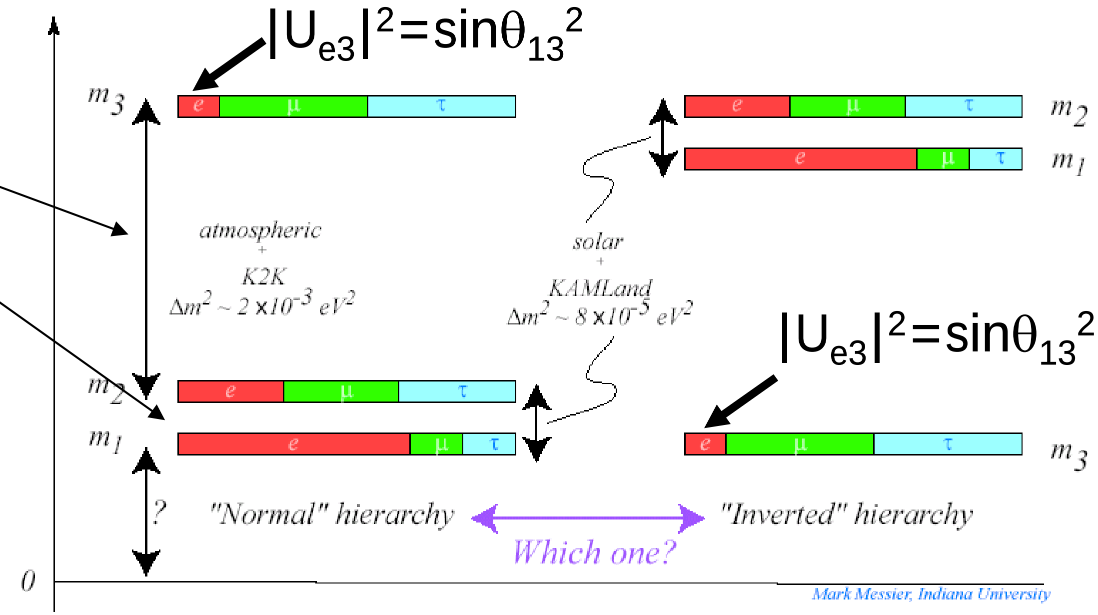
Present knowledge and next steps

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

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

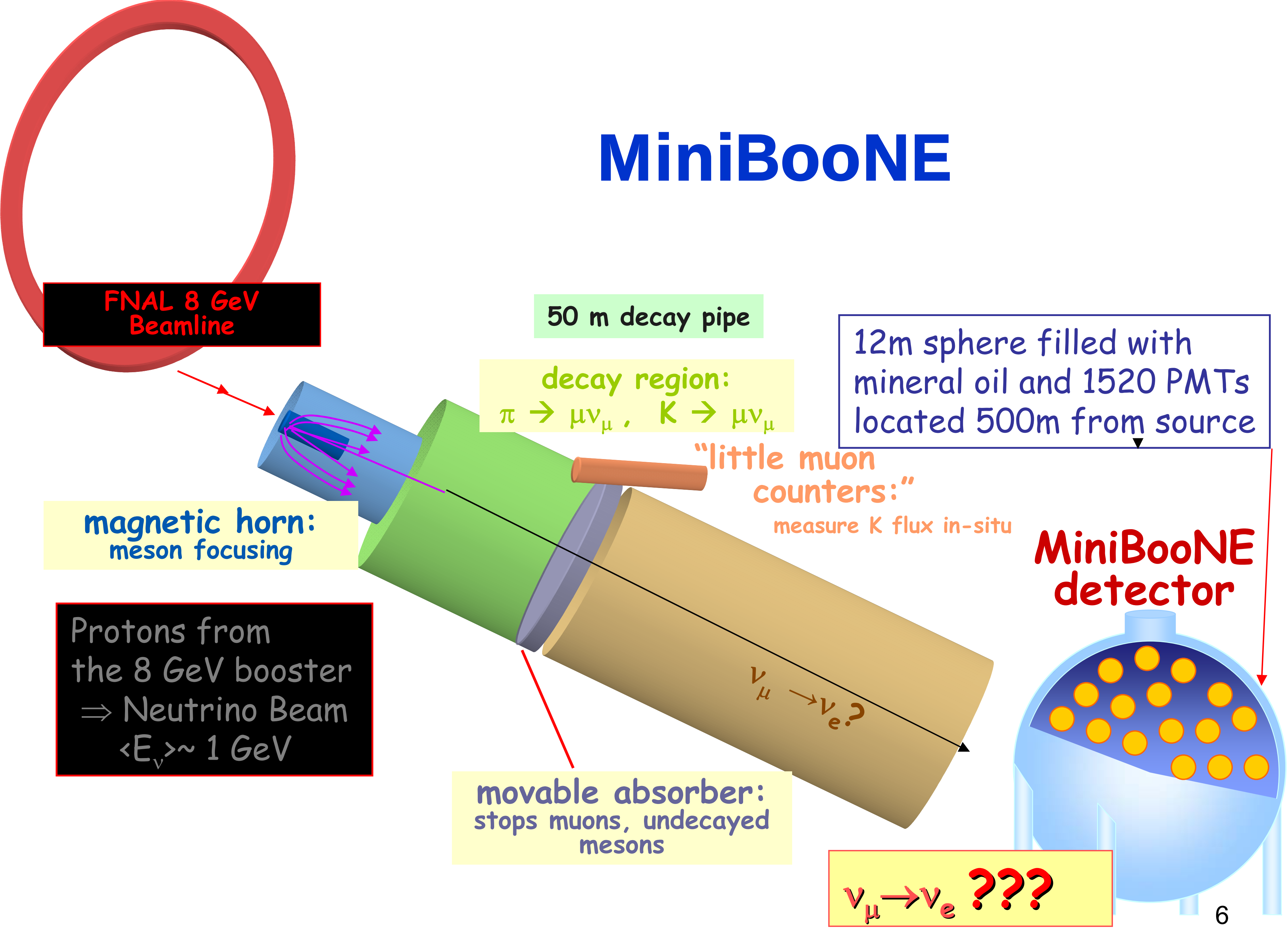
Large mixing { $\theta_{12} \sim 33^o$ $\theta_{23} \sim 45^o$

??



- Mixing angle θ_{13}
- Mass hierarchy (sign of Δm_{23}^2 $\rightarrow$ $m_3 > m_1$ 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_{23}^2)
  - Reactor-based ν_e disappearance: single purpose (θ_{13}), complementary
  - Accelerator SBL → LSND/MiniBooNE anomalies, sterile neutrinos (?)

MiniBooNE

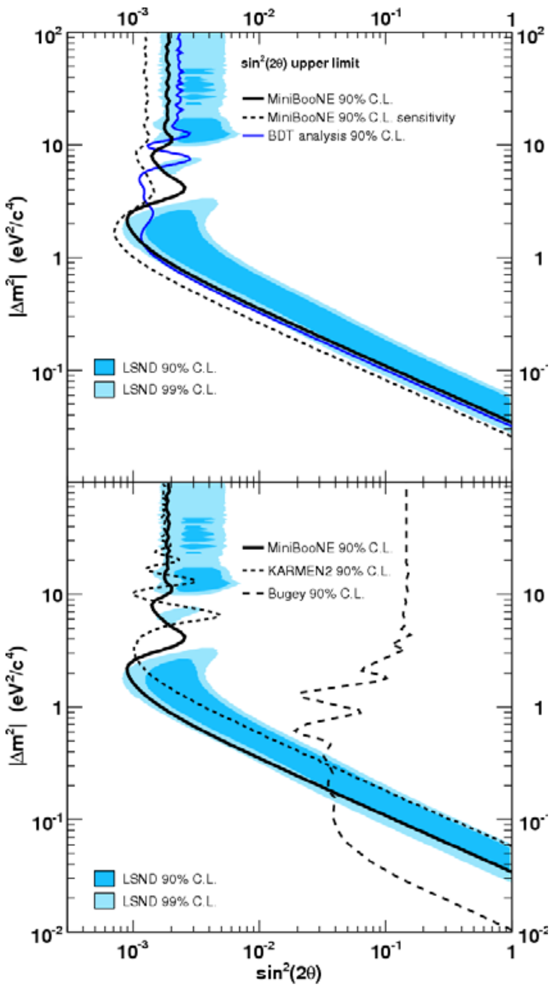


FNAL 8 GeV Beamline
50 m decay pipe
decay region:
π → μν_μ , K → μν_μ
12m sphere filled with mineral oil and 1520 PMTs located 500m from source
"little muon counters:"
measure K flux in-situ
magnetic horn:
meson focusing
MiniBooNE detector
Protons from the 8 GeV booster
⇒ Neutrino Beam
<E_ν>~ 1 GeV
ν_μ →ν_e?
movable absorber:
stops muons, undecayed mesons
ν_μ→ν_e ???

MiniBooNE results

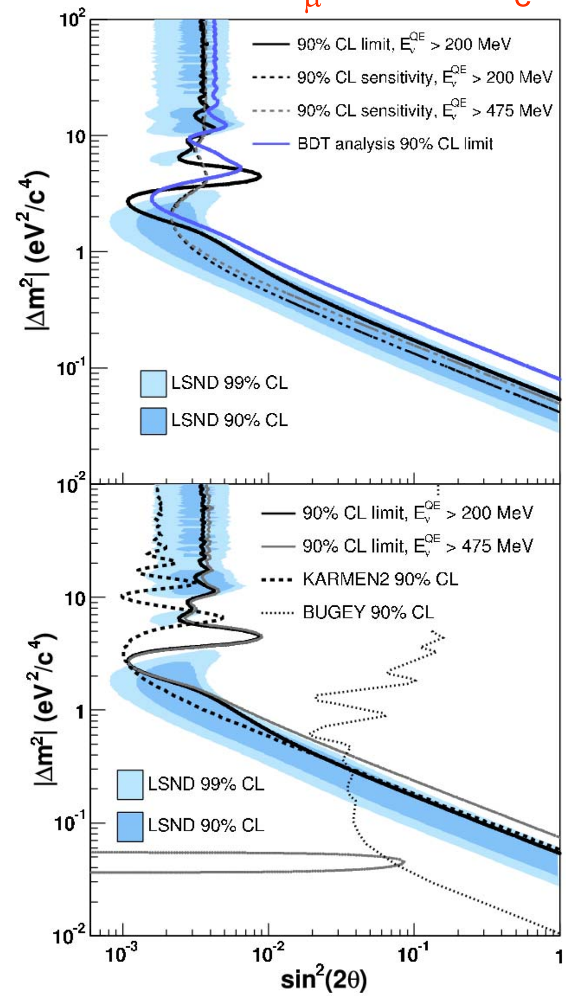
E_ν > 475 MeV

Neutrino run 2007 $\nu_\mu \to \nu_e$



5.58×10^{20} POT

Antineutrino run 2009 anti-$\nu_\mu \to$ anti-ν_e

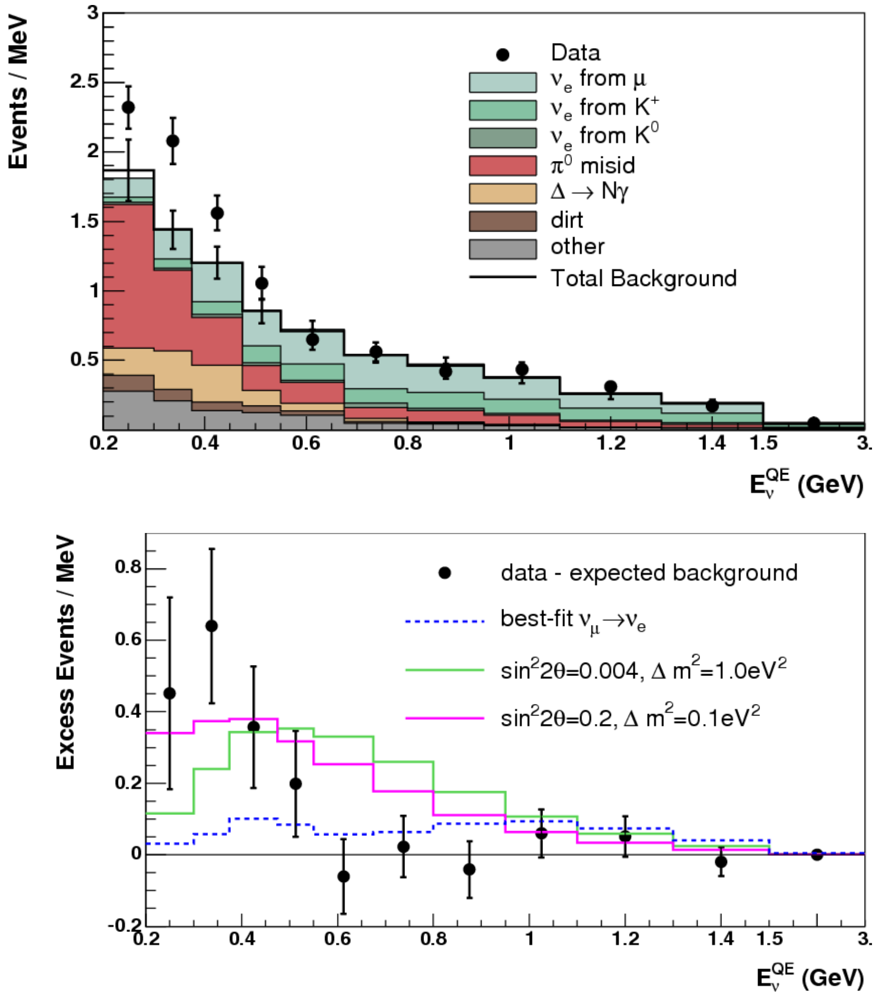


3.39×10^{20} POT

MiniBooNE anomaly

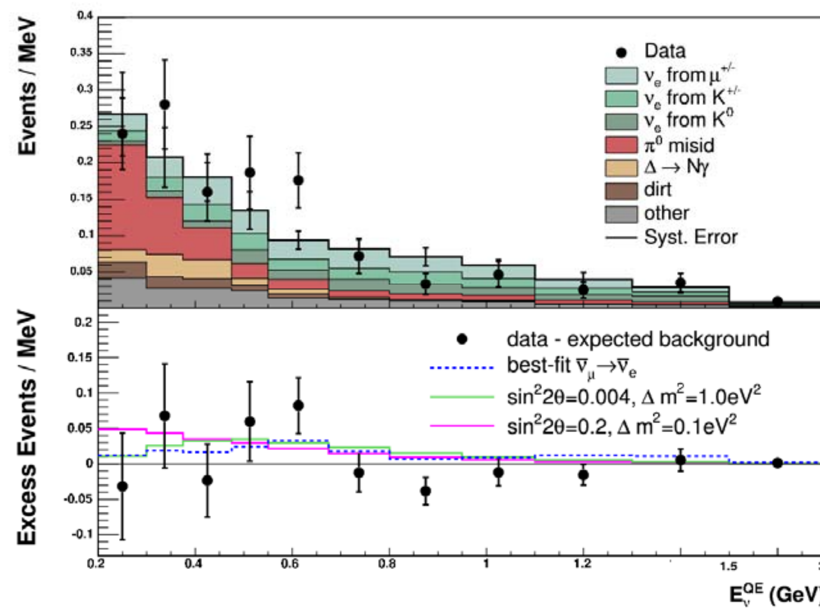
$\nu_\mu \to \nu_e$

arXiv:0812.2243 [hep-ex]



anti-ν_μ → anti-ν_e

arXiv:0904.1958 [hep-ex]



MiniBooNE anomaly

Event Sample	anti-ν_e analysis (3.39×10^{20} POT)	ν_e analysis (6.46×10^{20} POT)
200 − 475 MeV		
Data	61	544
Background	61.5 ± 11.7	415.2 ± 43.4
Excess	−0.5 ± 11.7 (−0.04σ)	128.8 ± 43.4 (3.0σ)
475 − 1250 MeV		
Data	61	408
Background	57.8 ± 10.0	385.9 ± 35.7
Excess	3.2 ± 10.0 (0.3σ)	22.1 ± 35.7 (0.6σ)

Possible explanations

Anomaly Mediated Neutrino-Photon Interactions at Finite Baryon Density
Jeffrey A. Harvey, Christopher T. Hill, & Richard J. Hill, arXiv:0708.1281

CP-Violation 3+2 Model
Maltoni& Schwetz, arXiv:0705.0107; T. Goldman, G. J. Stephenson Jr., B. H. J. McKellar, Phys. Rev. D75 (2007) 091301

Lorentz Violation
Katori, Kostelecky, & Tayloe, Phys. Rev. D74 (2006) 105009

CPT Violation 3+1 Model
Barger, Marfatia, & Whisnant, Phys. Lett. B576 (2003) 303

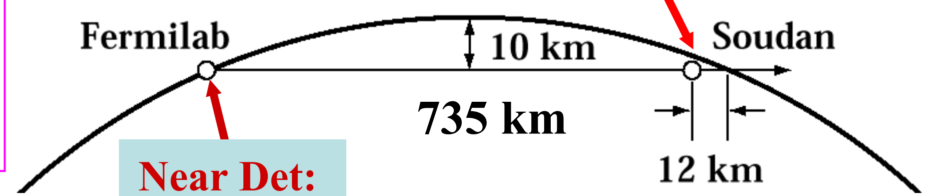
Heavy Sterile Neutrino Decay
S.N. Gninenko, arXiv:0902.3802

VSBL Electron Neutrino Disappearance
Carlo Giunti& Marco Laveder, arXiv: 0902:1992

MINOS

Precise study of "atmospheric" neutrino oscillations, using the NUMI beam and two detectors

Far Det: 5400 tons



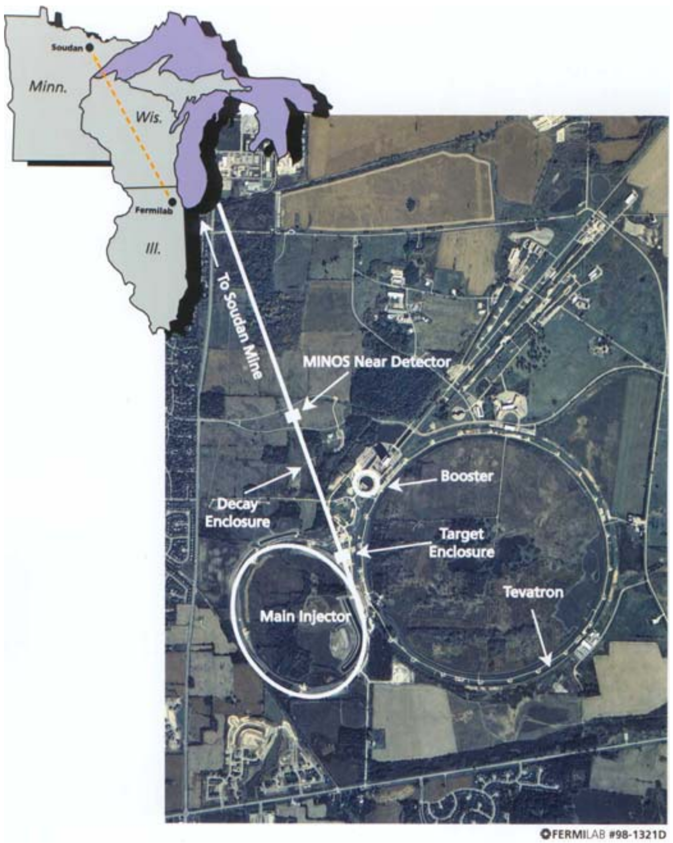
Near Det: 980 tons

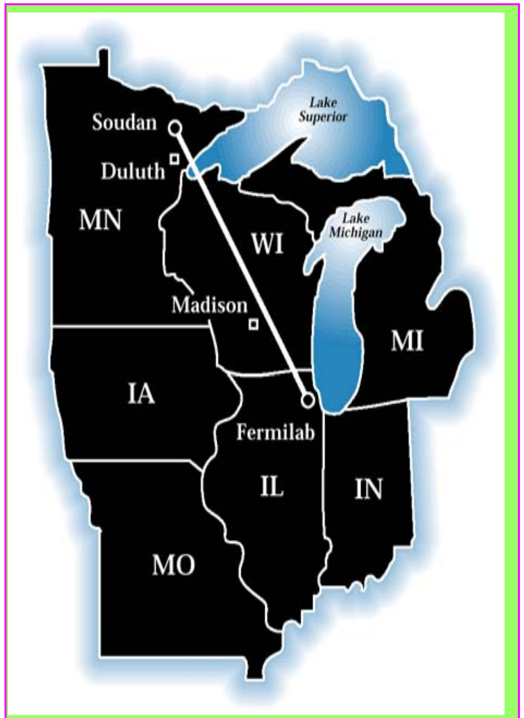
Beam: NuMI beam, 120 GeV Protons $\rightarrow \nu_\mu$- beam

Detectors: ND, FD

Far Det: 5.4 kton magnetized Fe/Sci Tracker/Calorimeter at Soudan, MN (L=735 km)

Near Det: 980 ton version of FD, at FNAL (L $\approx$ 1 km)





MINOS: $\nu_\mu \rightarrow \nu_s$

MINOS, PRL 101:221804,2008

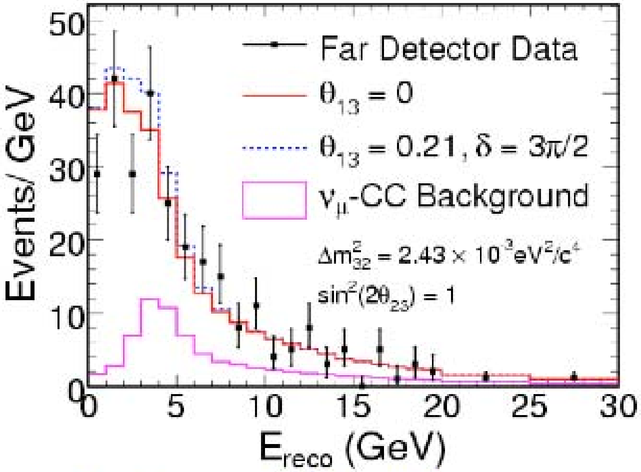
Neutral Current Analysis

- General NC analysis overview:
  - All active neutrino flavours participate in NC interaction
  - Mixing to a sterile-ν will cause a deficit of NC events in Far Det.
  - Assume one sterile neutrino and that mixing between ν_μ, ν_s and ν_τ occurs at a single Δm^2
- Survival and sterile oscillation probabilities become:

$$P(\nu_\mu - \nu_\mu) = 1 - \alpha_\mu \sin^2(1.27\Delta m^2 L/E)$$

$$P(\nu_\mu - \nu_s) = \alpha_s \sin^2(1.27\Delta m^2 L/E)$$

- ($\alpha_{\mu,s}$ = mixing fractions)

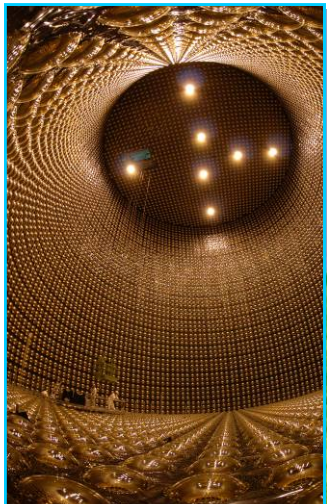


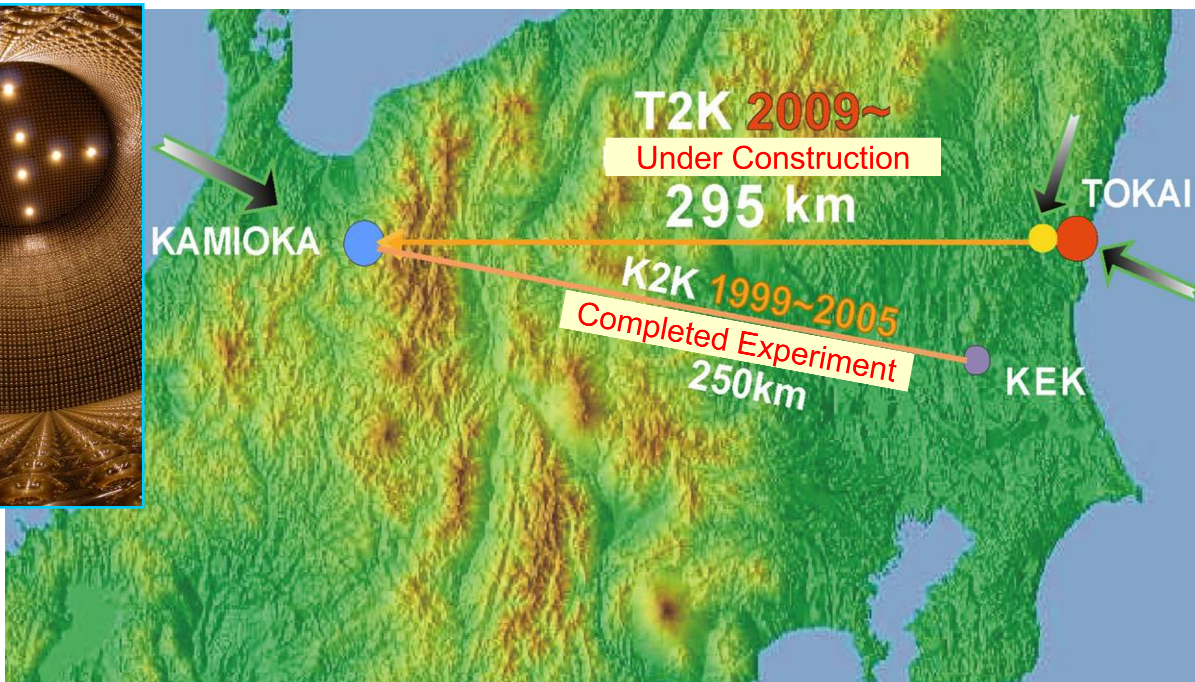
Simultaneous fit to CC and NC energy spectra yields the fraction of ν_μ that oscillate to ν_s:

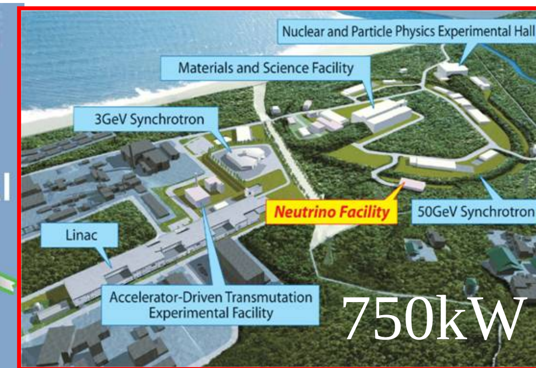
$$f_s = \frac{P(\nu_\mu \rightarrow \nu_s)}{1 - P(\nu_\mu \rightarrow \nu_\mu)} = 0.28^{+0.25}_{-0.28}\text{(stat.+syst.)}$$

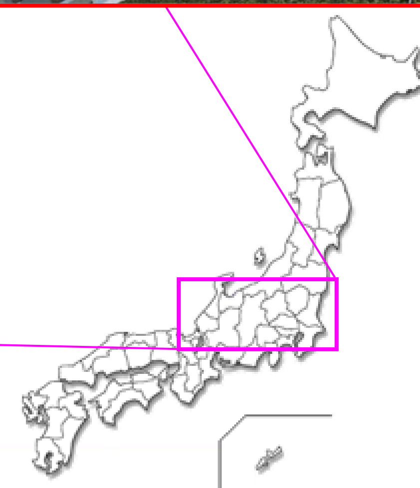
$$f_s < 0.68 \quad \text{(90\% C.L.)}$$

T2K (Tokai to Kamioka) LBL neutrino experiment

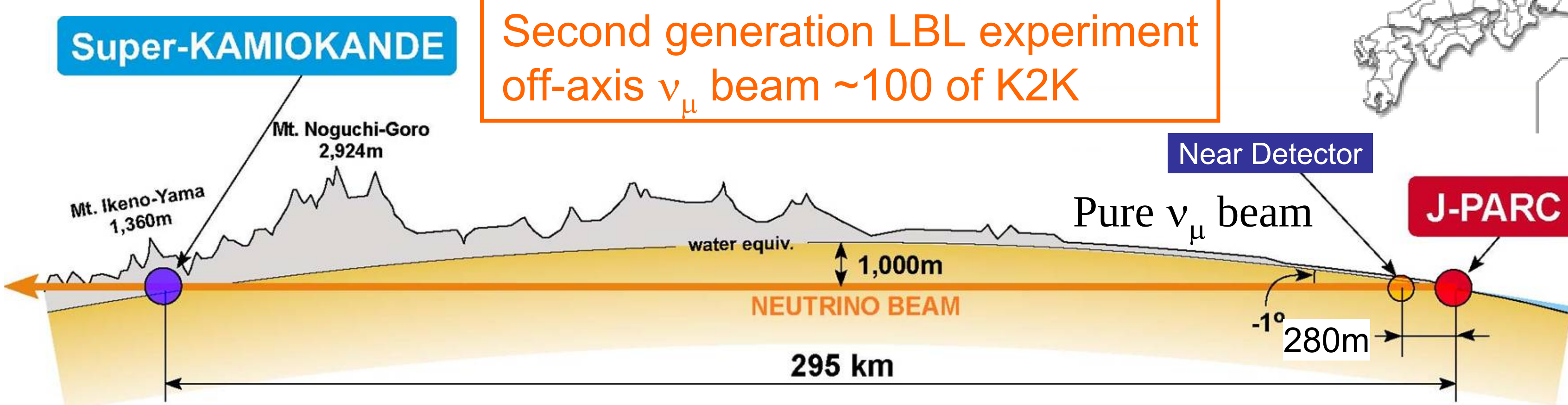








Second generation LBL experiment
off-axis ν_μ beam ~100 of K2K



T2K

SuperKamiokande

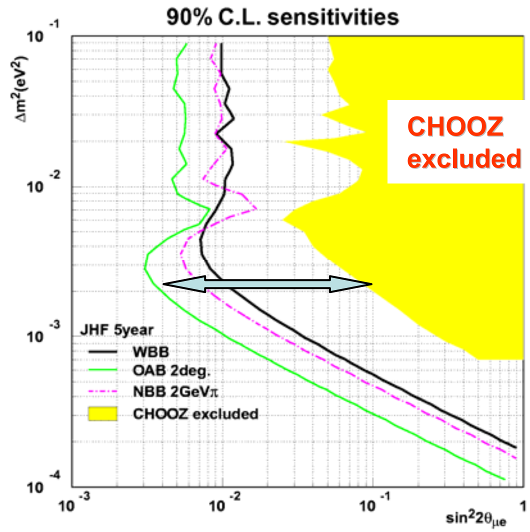
KEK

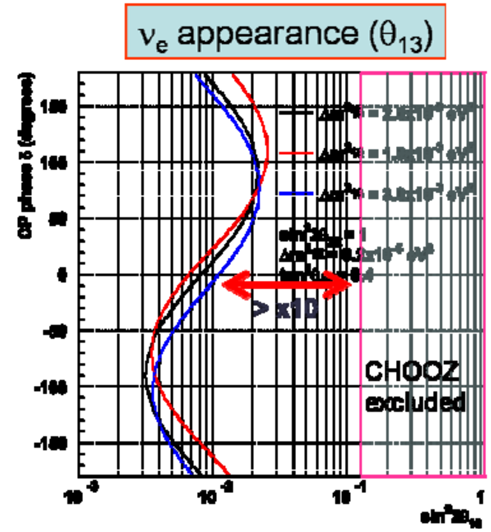
JPARC

Goals of T2K

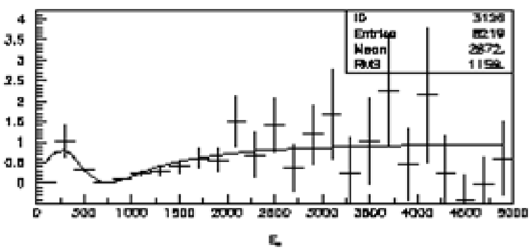
$\nu_\mu \rightarrow \nu_e$

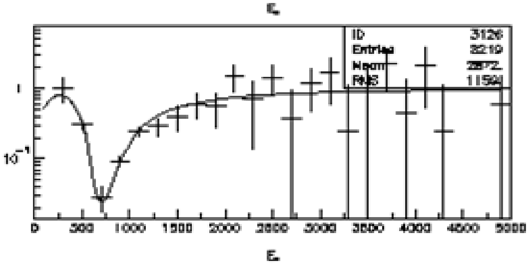
- Search for ν_e appearance
  sensitivity $\sin^2 2\theta_{13} \leq 0.01$





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

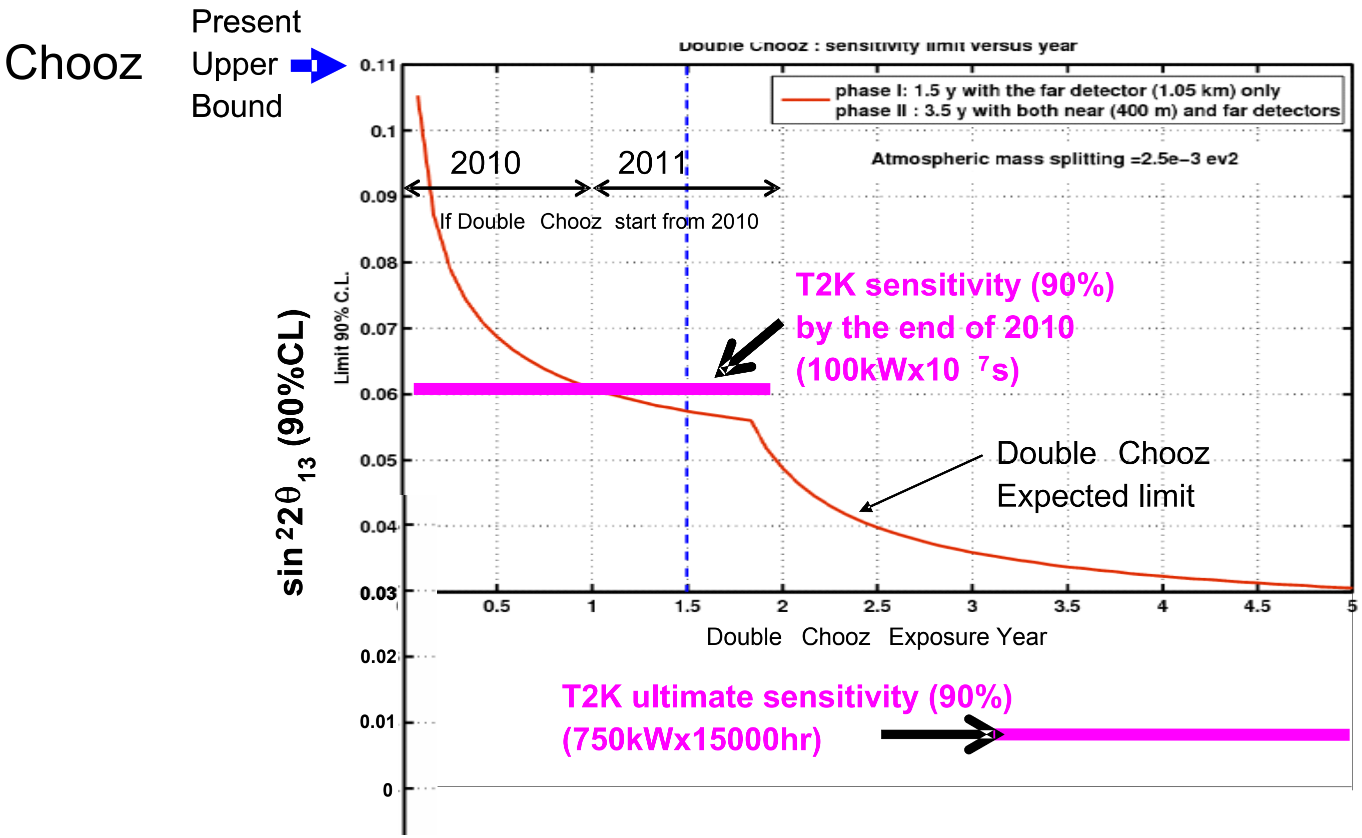




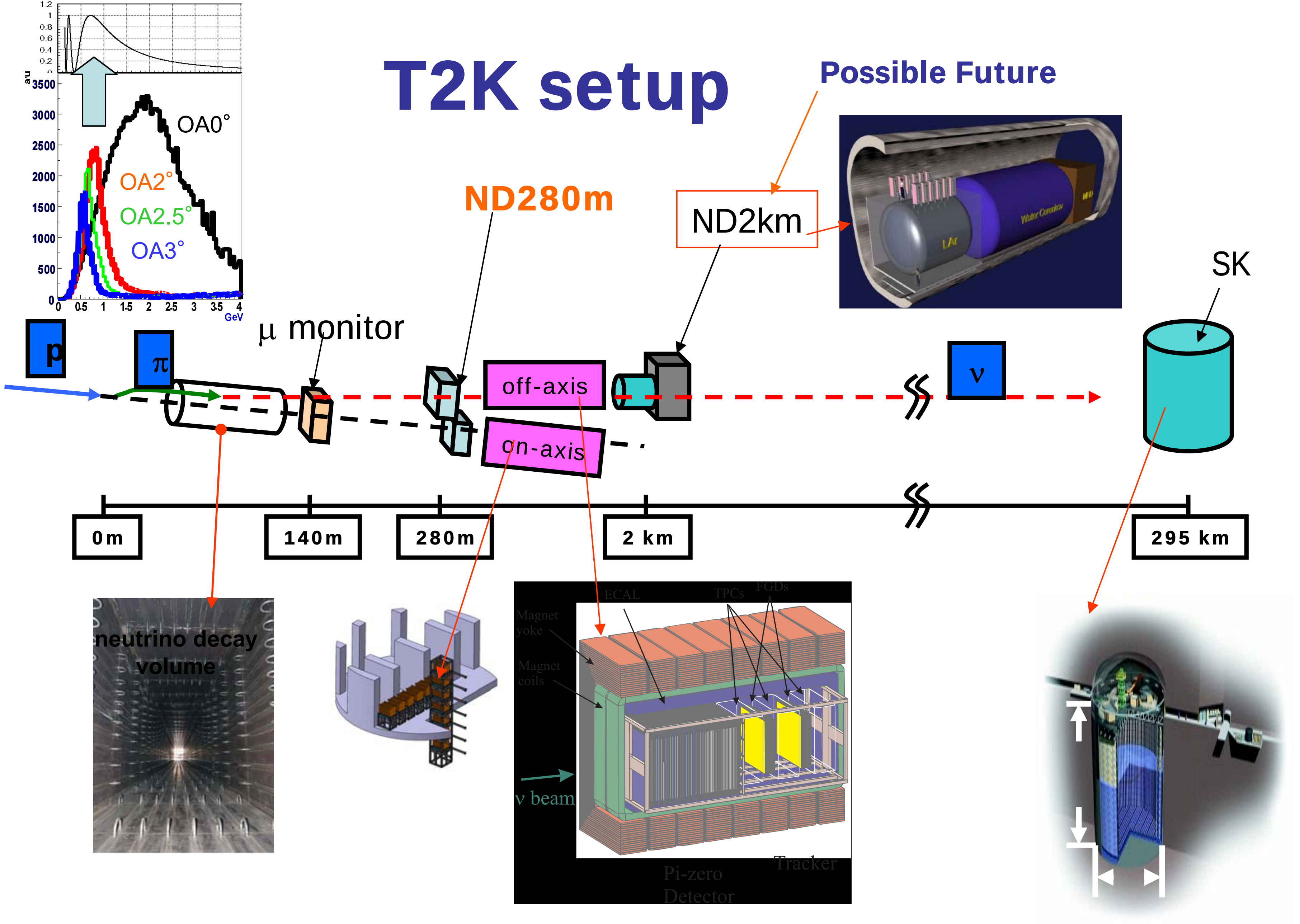
- Measurement of Δm^2_{23} with accuracy 2% and mixing angle with accuracy 1%
  $\delta(\sin^2 2\theta_{23}) \sim 0.01$
  $\delta(\Delta m^2_{23}) < 1\times10^{-4}$ eV^2

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

Expected sensitivity to θ_{13}

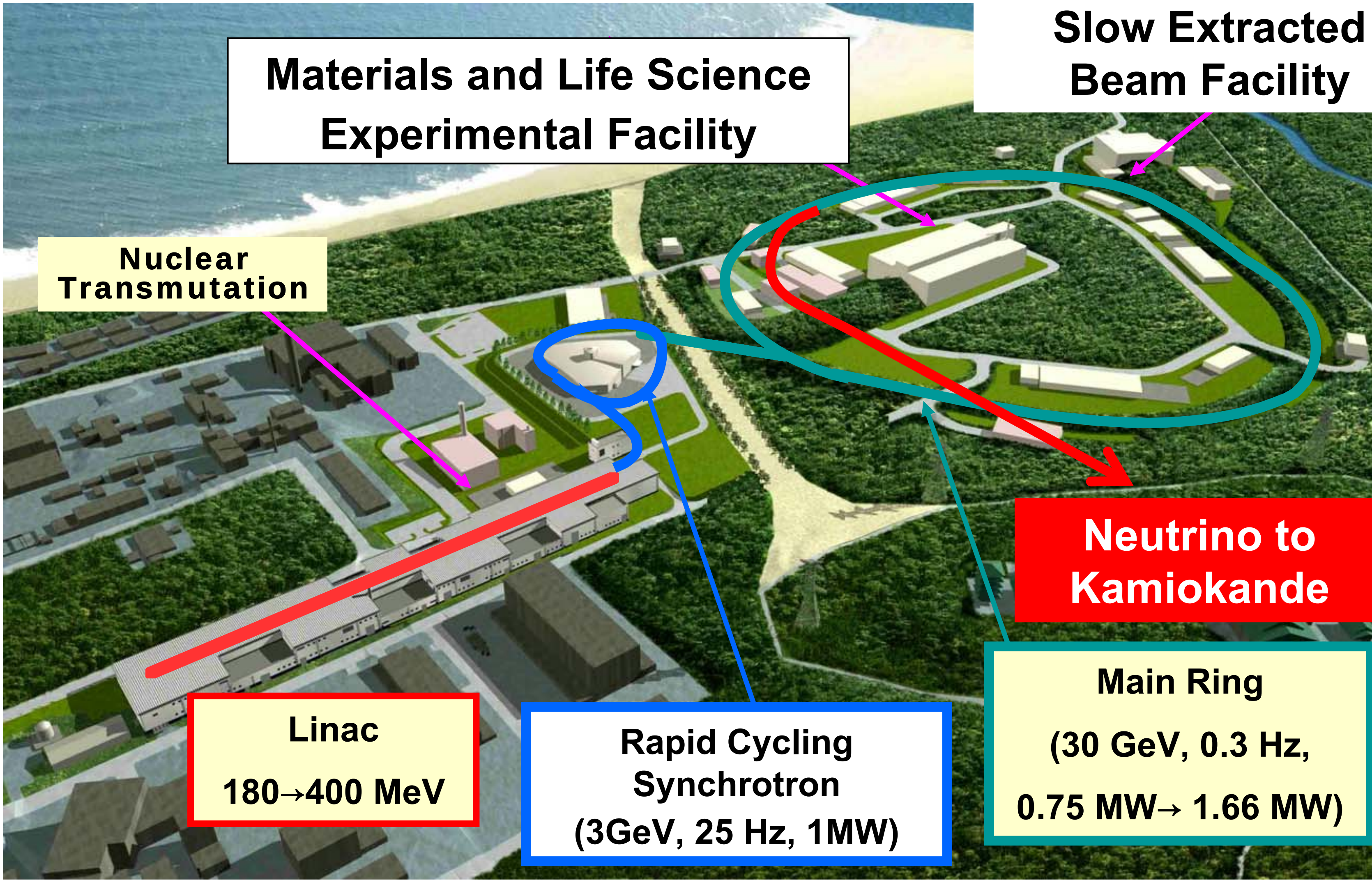


T2K setup



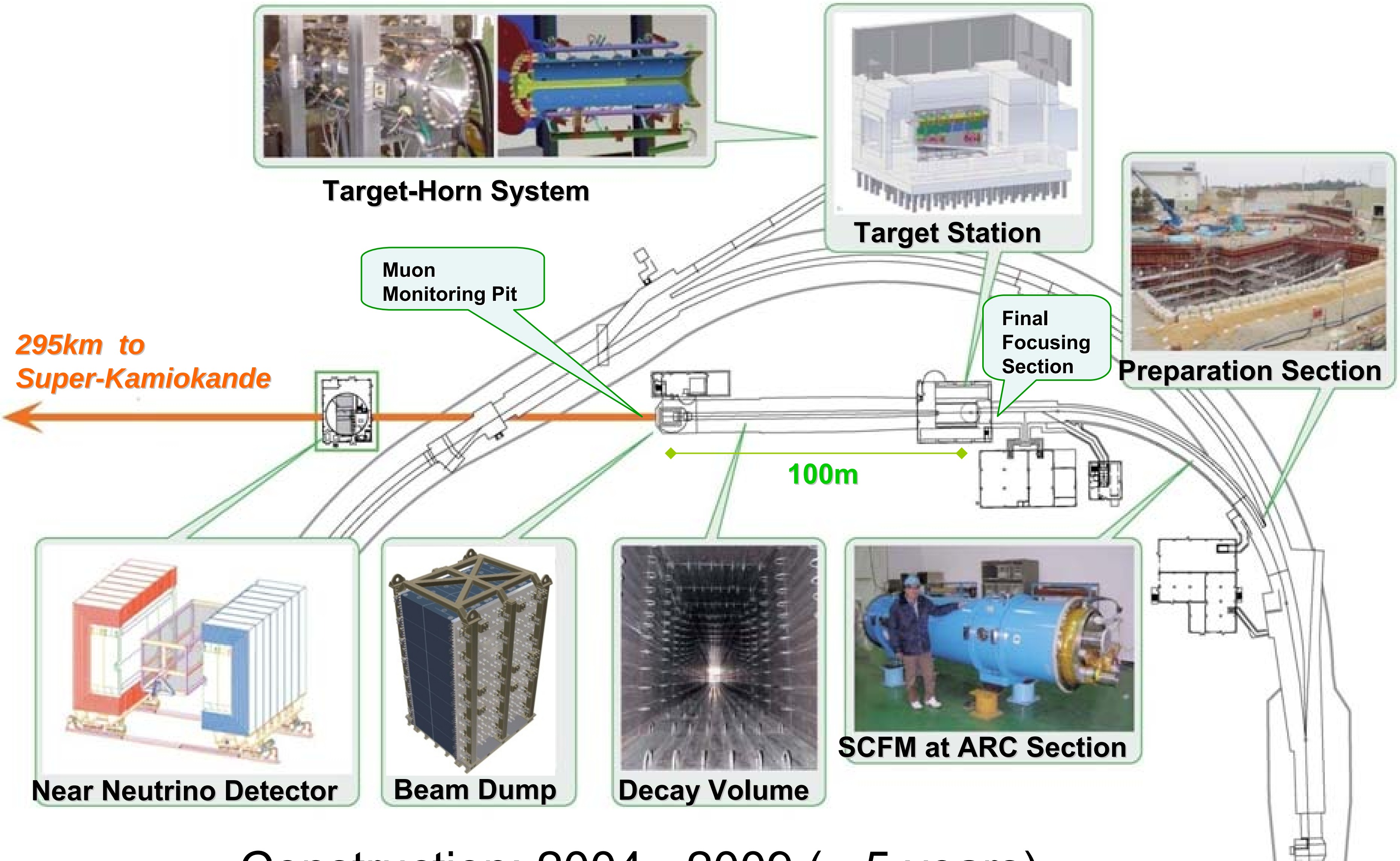
Possible Future
ND280m
ND2km
SK
OA0°
OA2°
OA2.5°
OA3°
GeV
a.u.
μ monitor
p
π
ν
off-axis
on-axis
0m
140m
280m
2 km
295 km
neutrino decay volume
ECAL
TPCs
FGDs
Magnet yoke
Magnet coils
ν beam
Tracker
Pi-zero Detector
LAr
Water Cerenkov

J-PARC



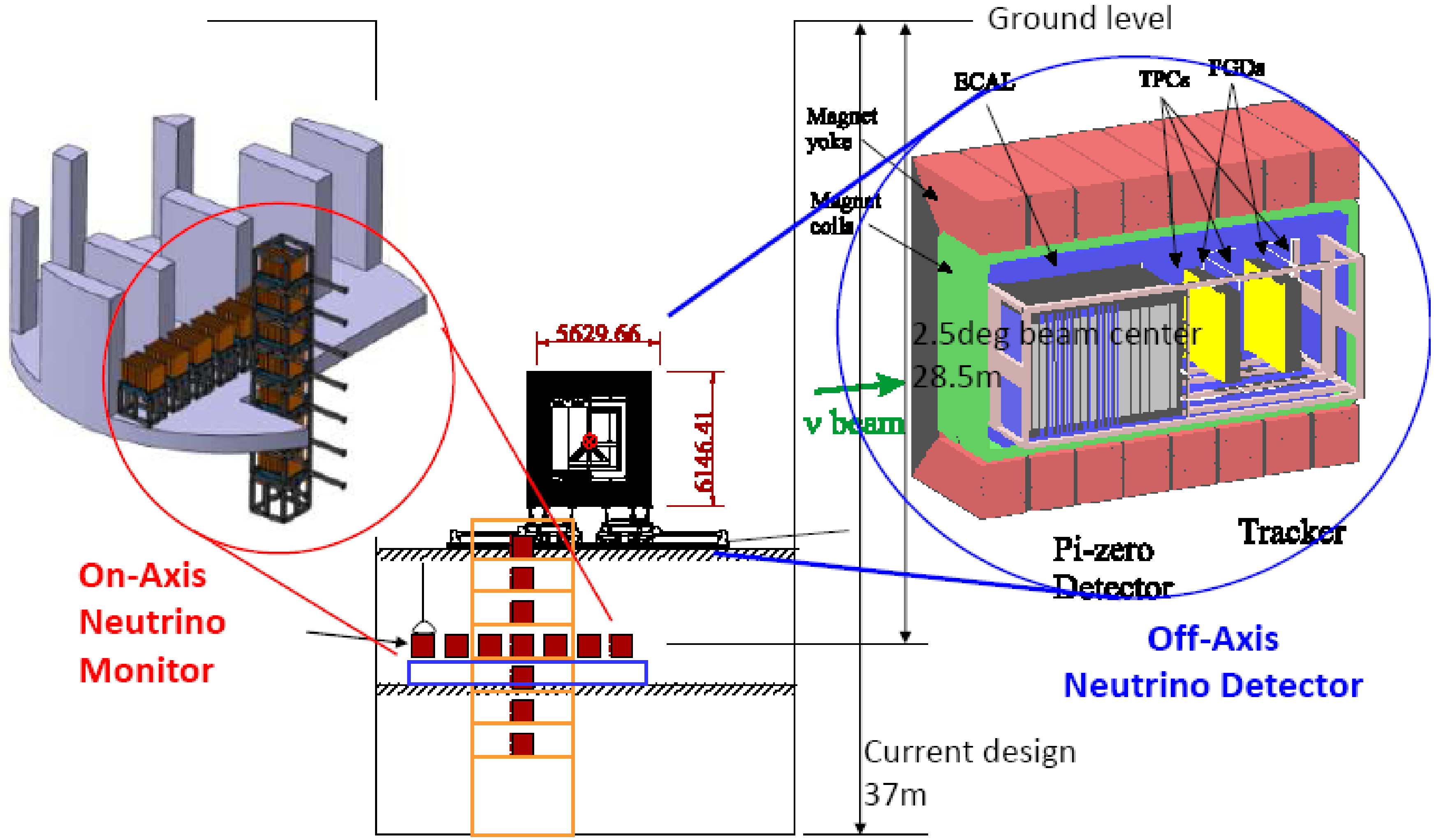
Materials and Life Science
Experimental Facility
Slow Extracted
Beam Facility
Nuclear
Transmutation
Neutrino to
Kamiokande
Main Ring
(30 GeV, 0.3 Hz,
0.75 MW→ 1.66 MW)
Linac
180→400 MeV
Rapid Cycling
Synchrotron
(3GeV, 25 Hz, 1MW)

Neutrino BeamLine



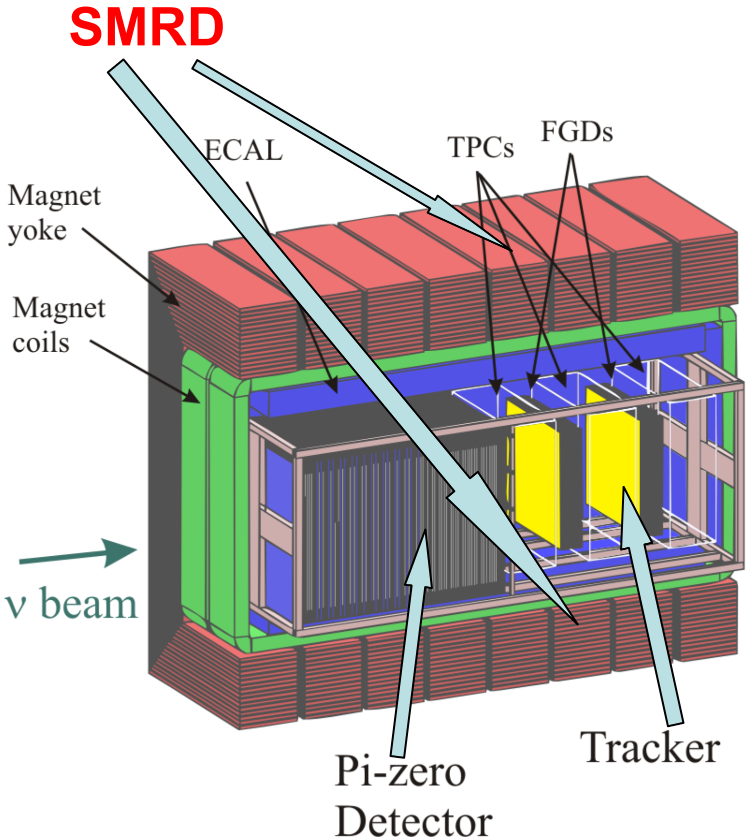
Construction: 2004 - 2009 (~ 5 years)

Near Neutrino Detectors



2

ND280 Off-axis Detector



280m downstream from pion production target

UA1/NOMAD CERN magnet
operated at 0.2 T magnetic field

Tracker: Optimized for CC interactions measurments

- Fine Grained Detector (FGD)
  - measure ν beam flux, E_ν spectrum, flavor composition through CC ν-interactions,
  - backgrounds CC-1π
  - water and scintillator target
- Time Projection Chamber (TPC)
  - measure charged particle momenta, particle ID via dE/dx
  - measure backgrounds/pion cross section

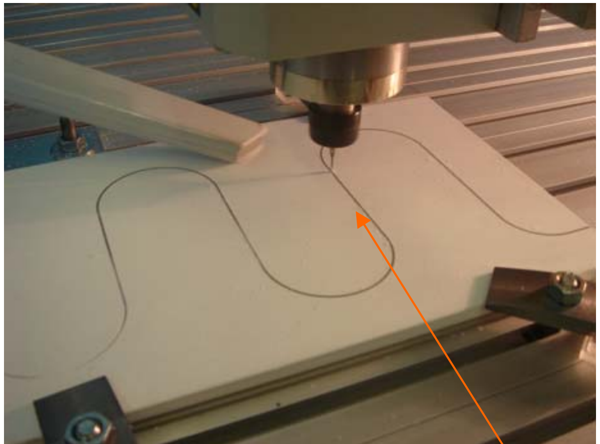
Pi-Zero Detector (P0D)
- Optimized for NC π^0 measurement
- measure ν_e contamination

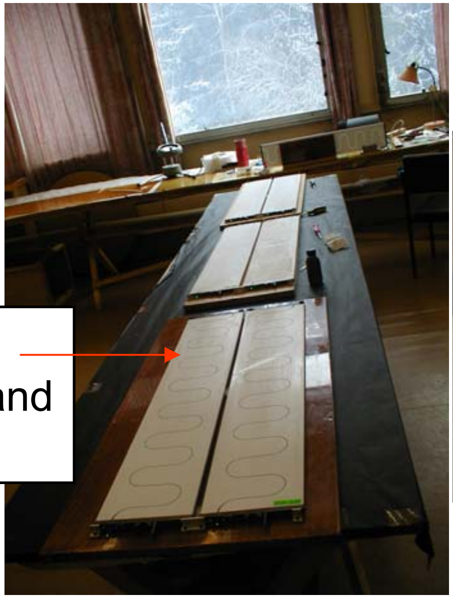
Electromagnetic Calorimeter (ECAL)
- Photon detection (from π^0) in P0D and tracker
- charge particle ID and reconstruction

Side Muon Range Detector (SMRD)
- measure momentum for lateral muons
- cosmic rays trigger

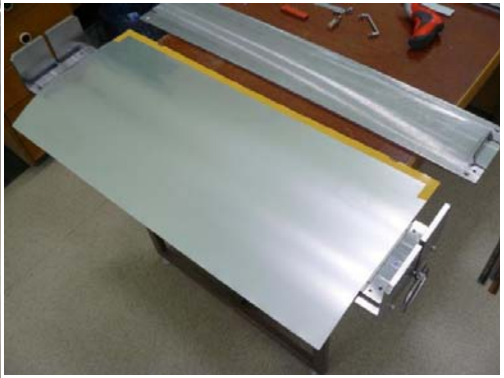
SMRD detectors

INR Workshop

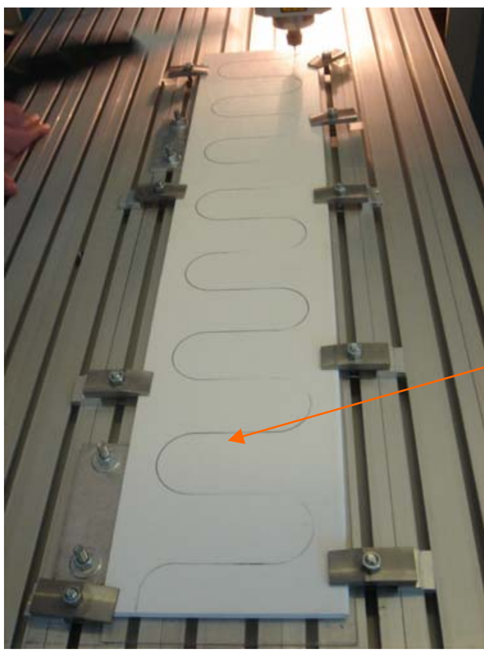




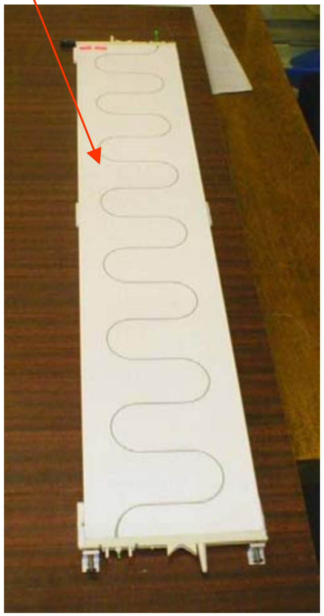
stainless steel container



Y11 fibers embedded and glued



Preparation of S-grooves

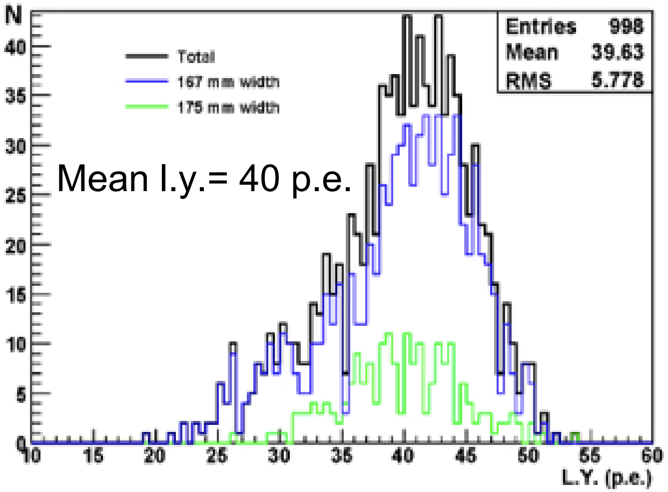


Ready for shipment

2130 SMRD detectors
are manufactured at INR in 2007-2009

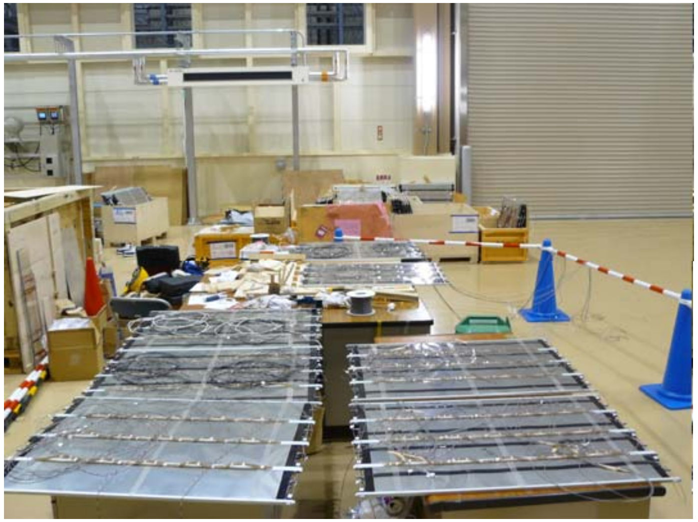
Completed February 2009

Shipped to JPARC in March 2009

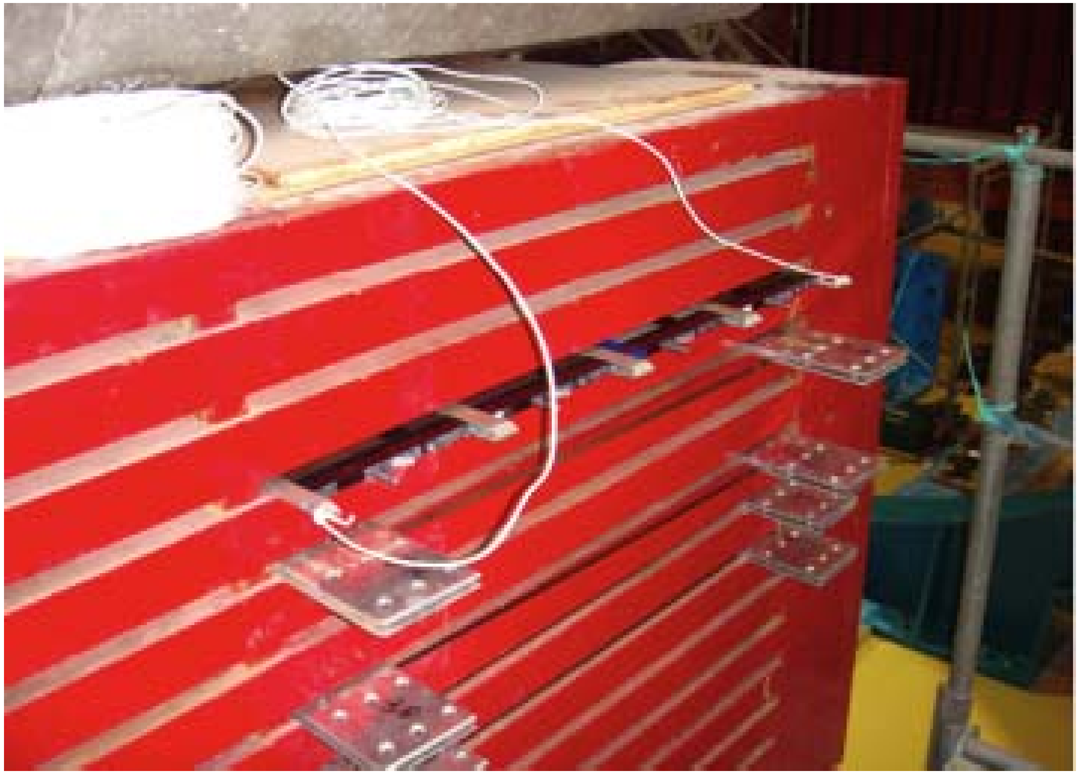


Assembly at JPARC

Assembly of SMRD modules at JPARC



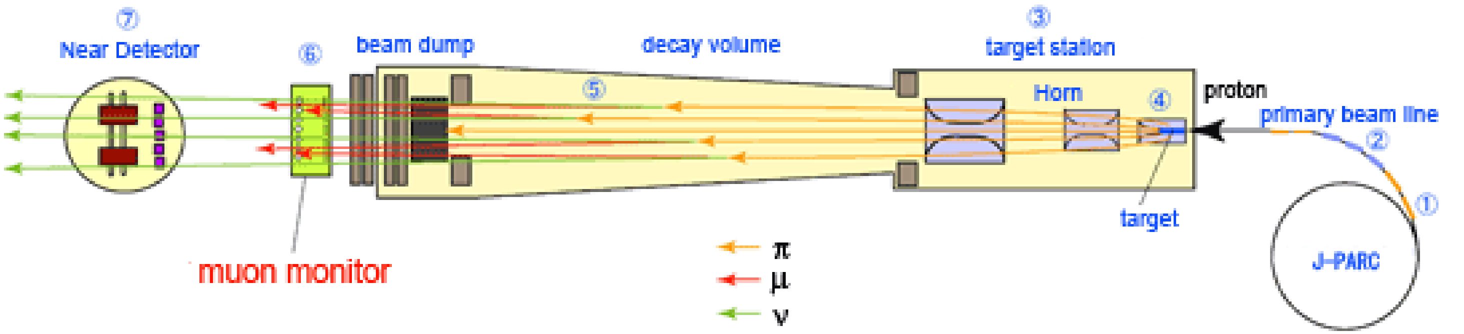
Detectors in UA1 magnet

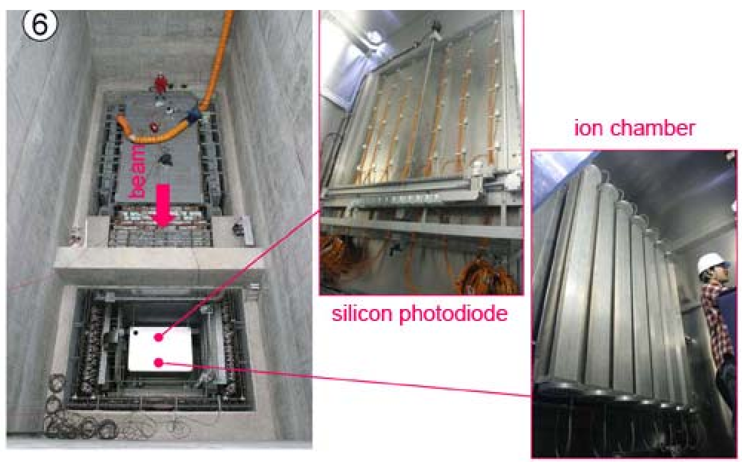


SMRD module (4 detectors) installed into magnet yoke

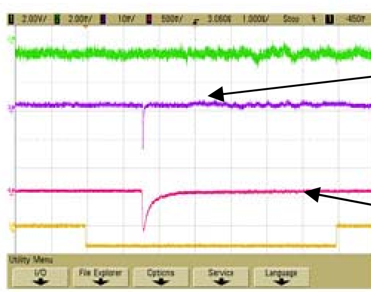
About 40% installed by 1 May 2009

First ν's for T2K





Muon signals
24 April 2009



Silicon photodiode

Scintillaotr counter

T2K Physics run

Beam commissioning: April-May 2009, Detector completion: Fall 2009

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)

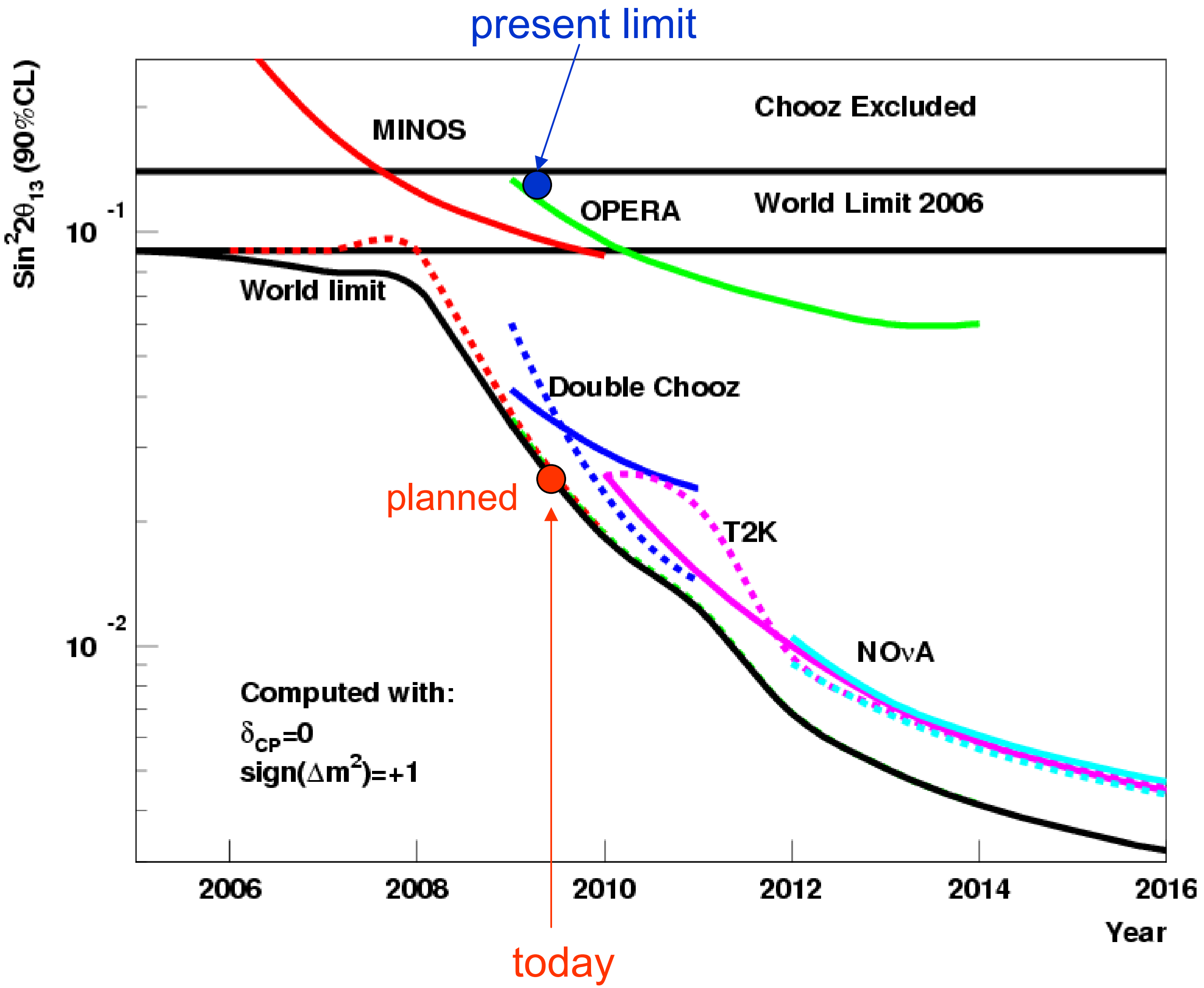
	null oscillation	oscillation
All	183.2	64.4
CCQE	118.0	22.9
CC non-QE	58.7	35.1
NC	6.5	6.5

oscillation parameters

$\sin^2 2\theta_{23} = 1.0$
$\Delta m^2_{23} = 2.4 \times 10^{-3}$ eV^2
L = 295 km

PREDICTIONS FOR SENSITIVITY TO θ_{13}

A.Blondel et al. hep-ex/0606111



Conclusion

MINOS, OPERA	data taking
MiniBooNe	new anomaly appears run with anti-ν beam
T2K-I	first neutrino beam in April 2009 start data taking in December 2009
Nova	finally approved construction begins in May 2009
MicroBooNE	proposal
OscSNS ORNL	proposal

MicroBooNE and OscSNS ORNL proposals } LSND, MiniBooNE anomalies, sterile ν