Новые результаты в нейтринных ускорительных экспериментах

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Осцилляции нейтрино

MiniBooNE

MINOS

OPERA

T2K

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

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

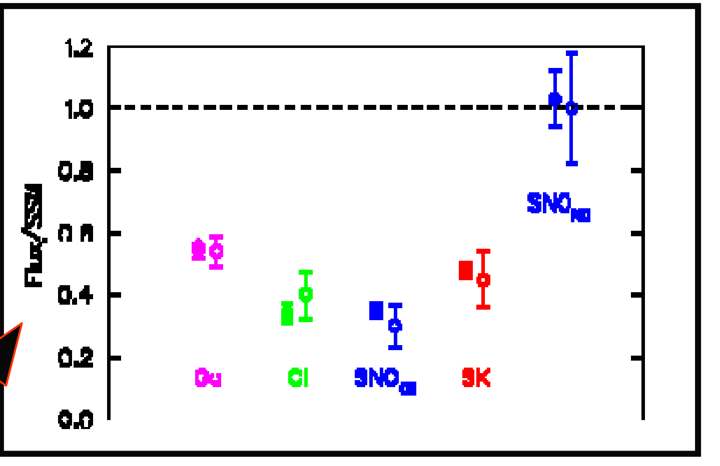
link between atmospheric and solar

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

δ - CP violating phase

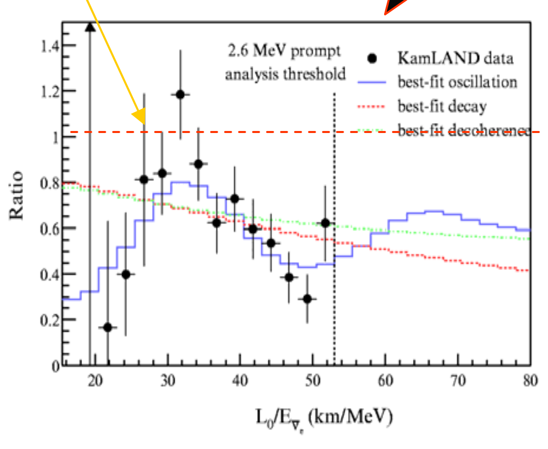
Solar neutrino oscillations

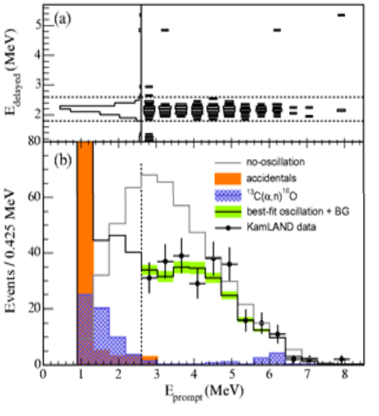
Solar neutrino experiments



No oscillation

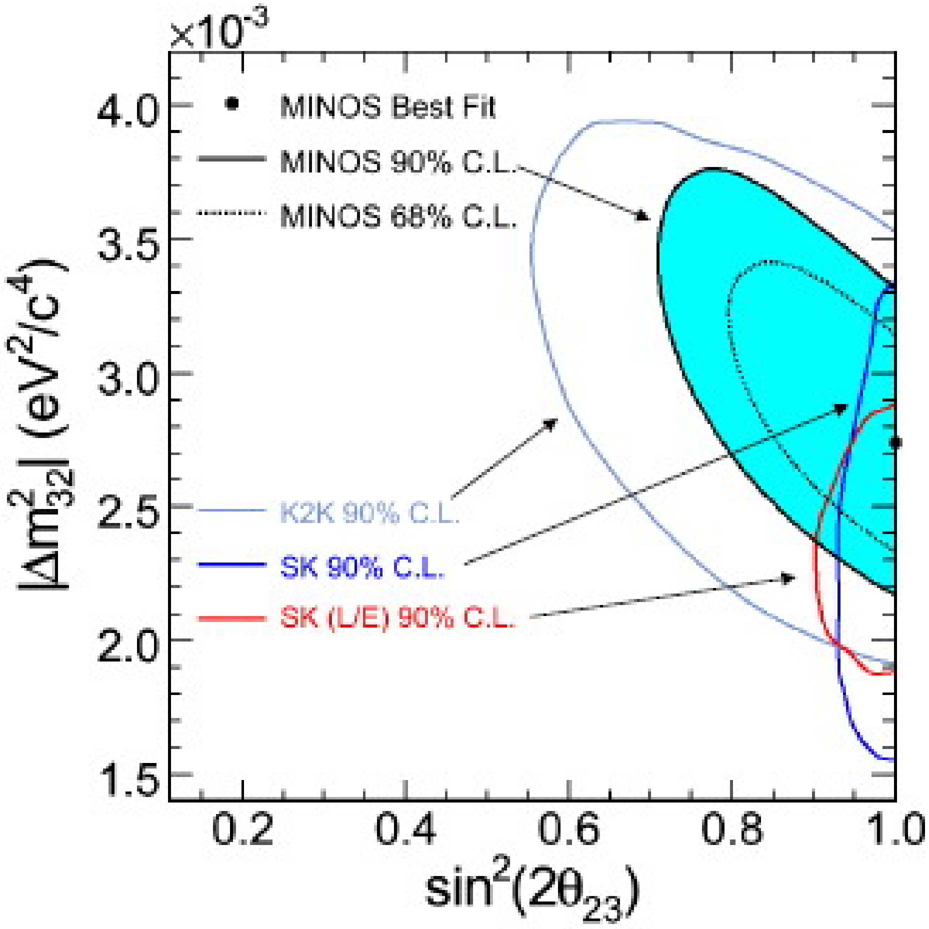
Kamland





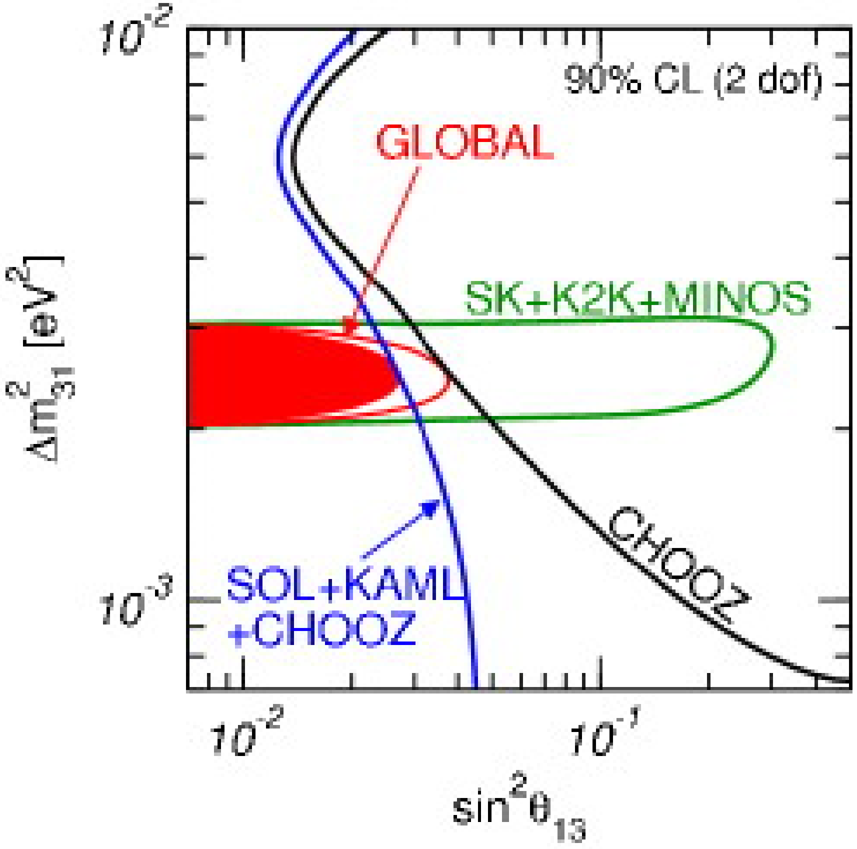
$\Delta m^2_{12} = (8.0\pm0.3)\text{x}10^{-5}\ eV^2 \quad \theta_{12} \sim 30^o$

SK – K2K - MINOS



$|\Delta m^2_{23}| \approx |\Delta m^2_{23}| = (2.5 \pm 0.2)\text{x}10^{-3}\ \text{eV}^2 \quad \theta_{23} \sim 45^o$

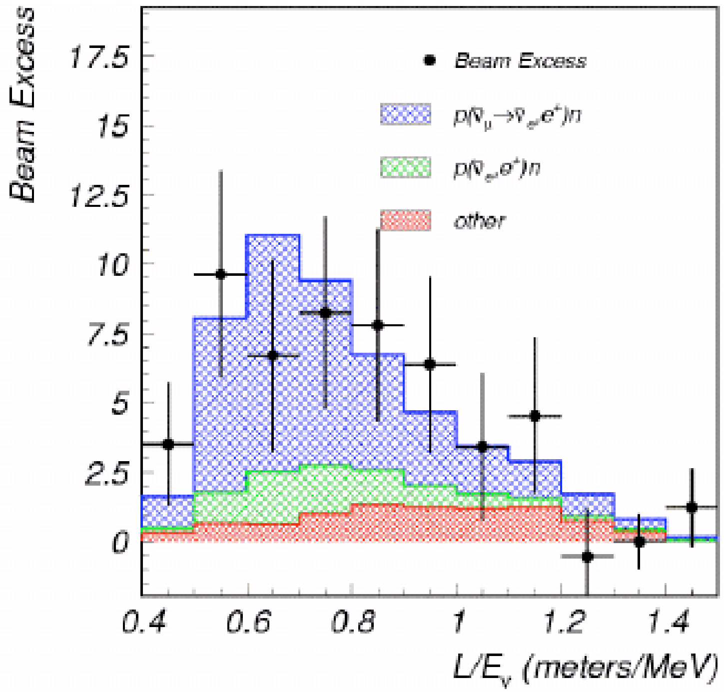
θ_{13}



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

LSND result

an excess of $\bar{\nu}_e$ events in a $\bar{\nu}_\mu$ beam,
$87.9 \pm 22.4 \pm 6.0$ (3.8σ)



Points -- LSND data
Signal (blue)
Backgrounds (red, green)

LSND Collab, PRD 64, 112007

Δm^2 = 0.2 – 10 eV^2 best fit: Δm^2 = 0.2–10 eV^2 $\sin^2 2\theta$ = 0.003

Neutrino masses and oscillations

3 families

Oscillation parameters

	central value	3σ interval
Δm^2_{12} (10^{-5} eV^2)	7.9	7.1 - 8.9
Δm^2_{31} (10^{-3}eV^2)	2.2	1.4 - 3.3
$\sin^2\theta_{12}$	0.31	0.24 - 0.40
$\sin^2\theta_{23}$	0.50	0.34 - 0.68
$\sin^2\theta_{13}$	0.0	<0.047

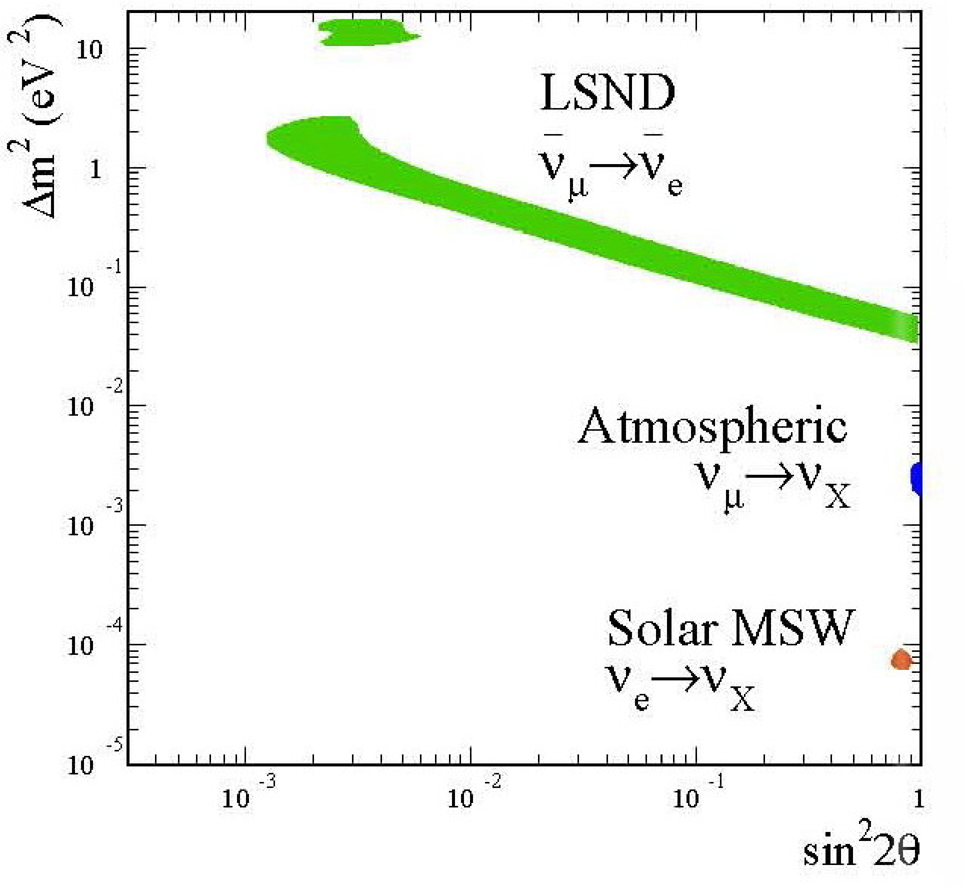
LSND → $\Delta m^2 = 0.2 – 10$ eV^2 → $m_\nu > 0.4$ eV

Mixing	Quarks	Leptons
1-2 θ_{12}	13^o	33^o
2-3 θ_{23}	2.3^o	35^o
1-3 θ_{13}	~ 0.5^o	<13^o

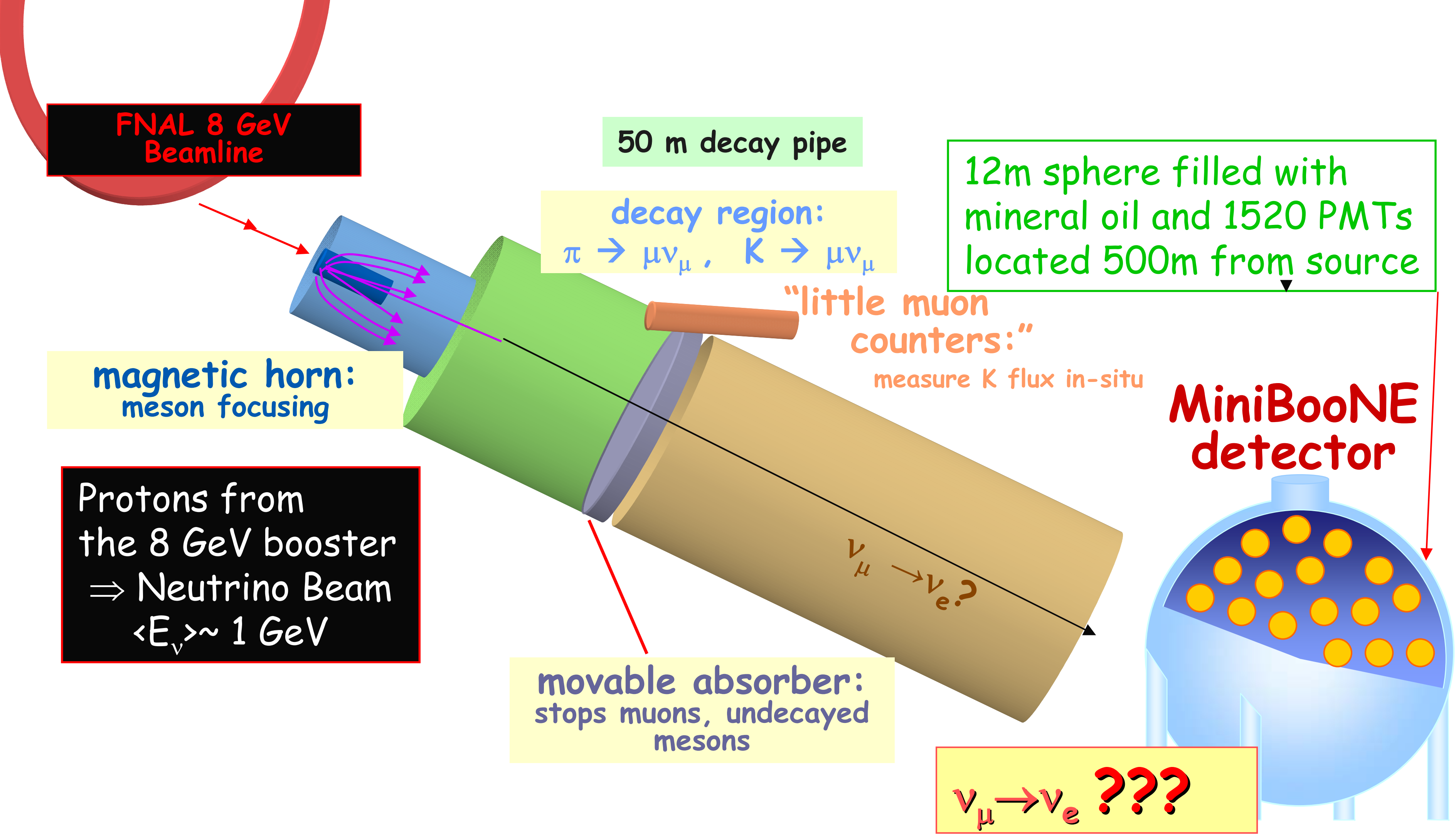
$$U_{CKM} = \begin{pmatrix} 1 & 0.2 & 0.005 \\ 0.2 & 1 & 0.04 \\ 0.005 & 0.04 & 1 \end{pmatrix} \qquad U_\nu = \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

$\delta_{CP} = ?$

Oscillations before first MiniBooNe result



MiniBooNE



FNAL 8 GeV Beamline
50 m decay pipe
decay region:
$\pi \rightarrow \mu\nu_\mu$, $K \rightarrow \mu\nu_\mu$
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
$\Rightarrow$ Neutrino Beam
$\langle E_\nu \rangle \sim 1$ GeV
$\nu_\mu \rightarrow \nu_e$?
movable absorber:
stops muons, undecayed mesons
$\nu_\mu \rightarrow \nu_e$???

MiniBooNE result

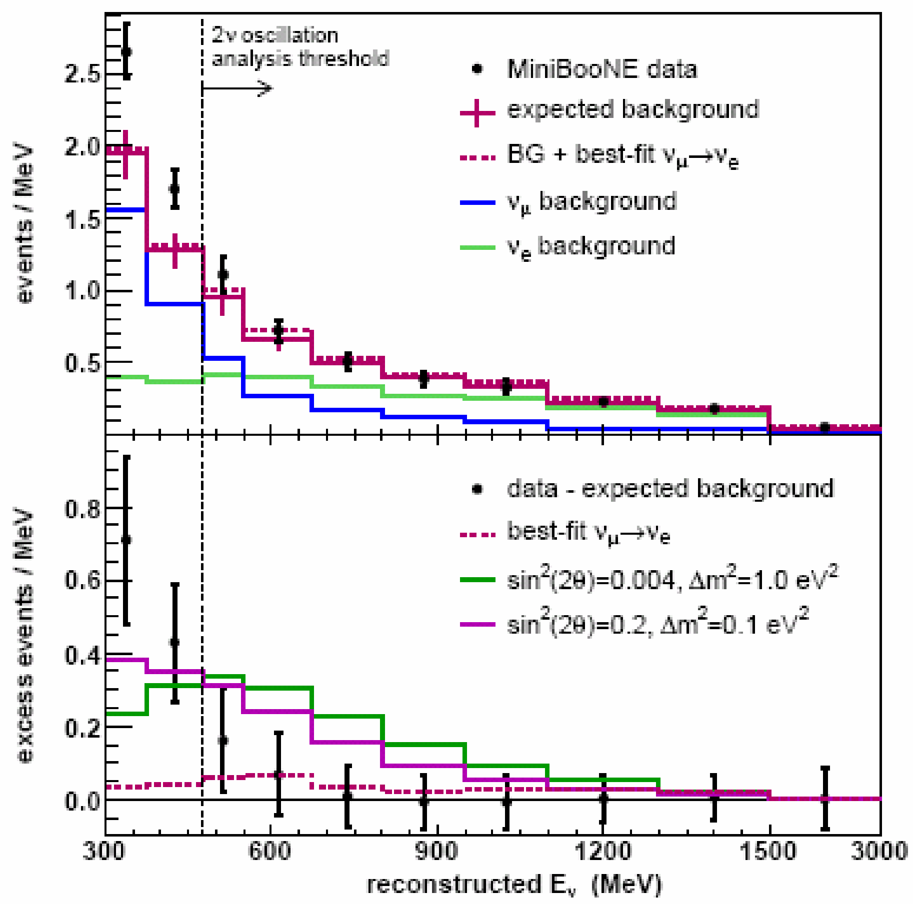
arXiv:0704.1500

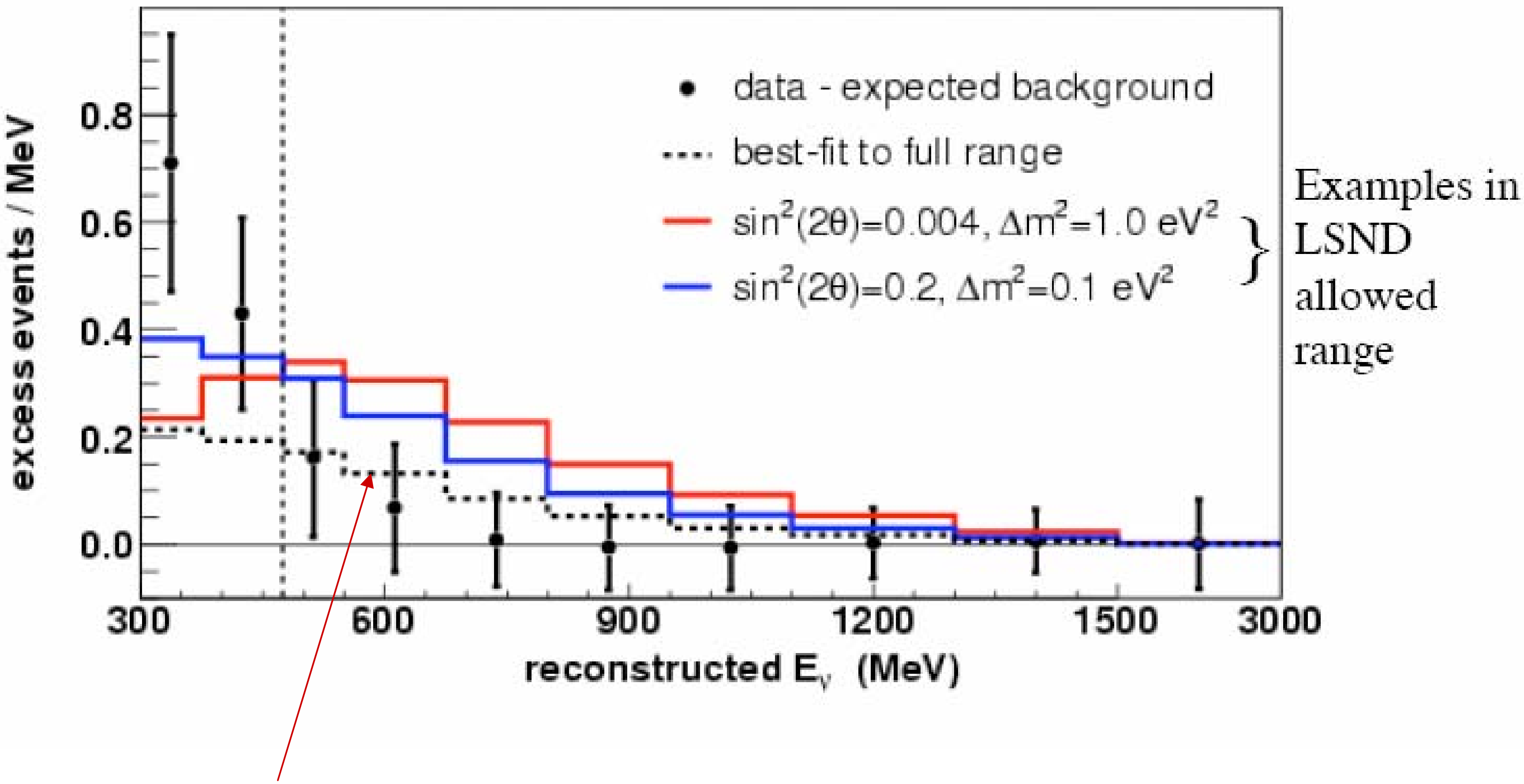
6 x10^20 POT

96 ± 17 ± 20 events above background, for 300<E_ν^{QE}<475MeV

Deviation: 3.7σ

Background-subtracted:

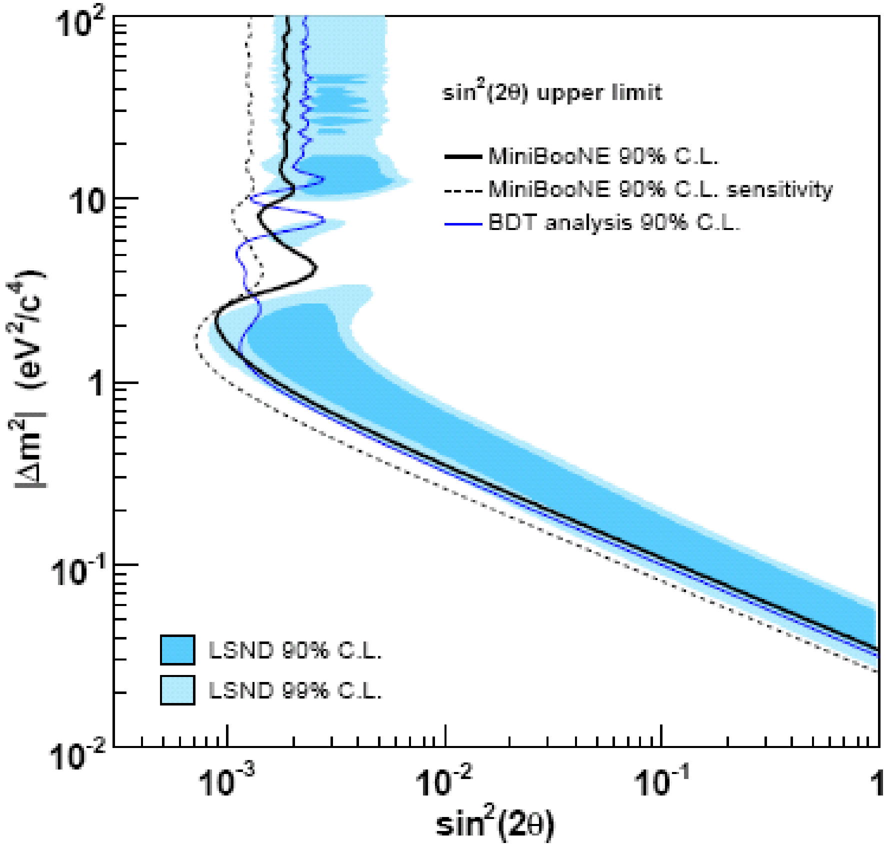




Best Fit (dashed): $(\sin^2 2\theta, \Delta m^2) = (1.0, 0.03\ \mathrm{eV}^2)$

χ^2 Probability: 18%

MiniBooNE is incompatible with a $\nu_\mu \rightarrow \nu_e$ appearance only interpretation of LSND at 98% CL



However
- **$\nu_\mu \rightarrow \nu_e$ (LSND anti-nu)**
- **excess at low energy**

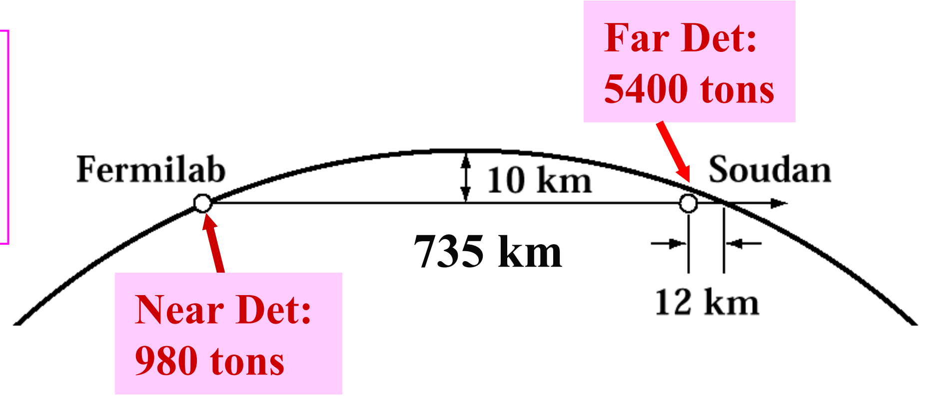
Antineutrino run since Summer 2006

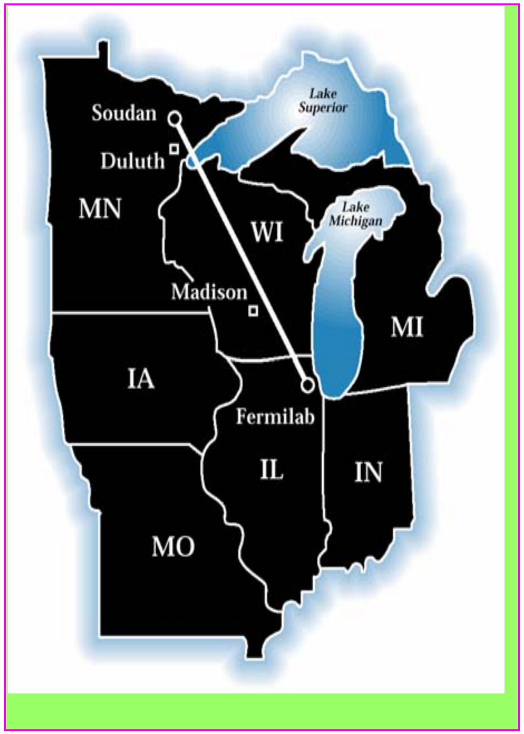
M.Maltoni, T.Schwetz
arXiv:0705.0104 [hep-ph]

3+2 scheme
CP-violation

MINOS

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





Beam: NuMI beam, 120 GeV Protons → ν_μ- beam

Detectors: ND, FD

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

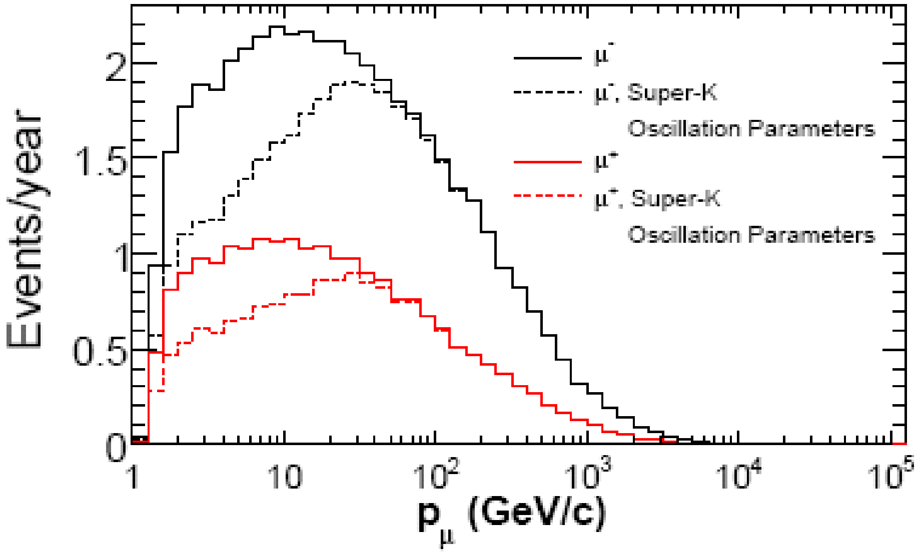
Near Det: 980 ton version of FD, at FNAL (L ≈ 1 km)

MINOS new results

Measurement of muon momentum and charge sign

Atmospheric neutrino-induced muons in Far detector
854 live days → 140 muons

hep-ex/0701045



$$\mathcal{R} = \frac{R^{data}_{L/H+U}}{R^{MC}_{L/H+U}} = 0.65^{+0.15}_{-0.12}(\text{stat}) \pm 0.09(\text{syst})$$

1 if no oscillations

$$\hat{\mathcal{R}}_{CPT} = \frac{R^{data}_{\mu^-/\mu^+}}{R^{MC}_{\mu^-/\mu^+}} = 0.72^{+0.24}_{-0.18}(\text{stat})^{+0.08}_{-0.04}(\text{syst})$$

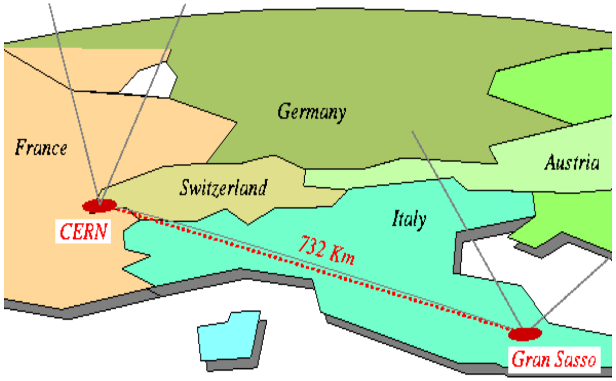
1 if CPT =1

OPERA

$\nu_\mu \rightarrow \nu_\tau$ direct search

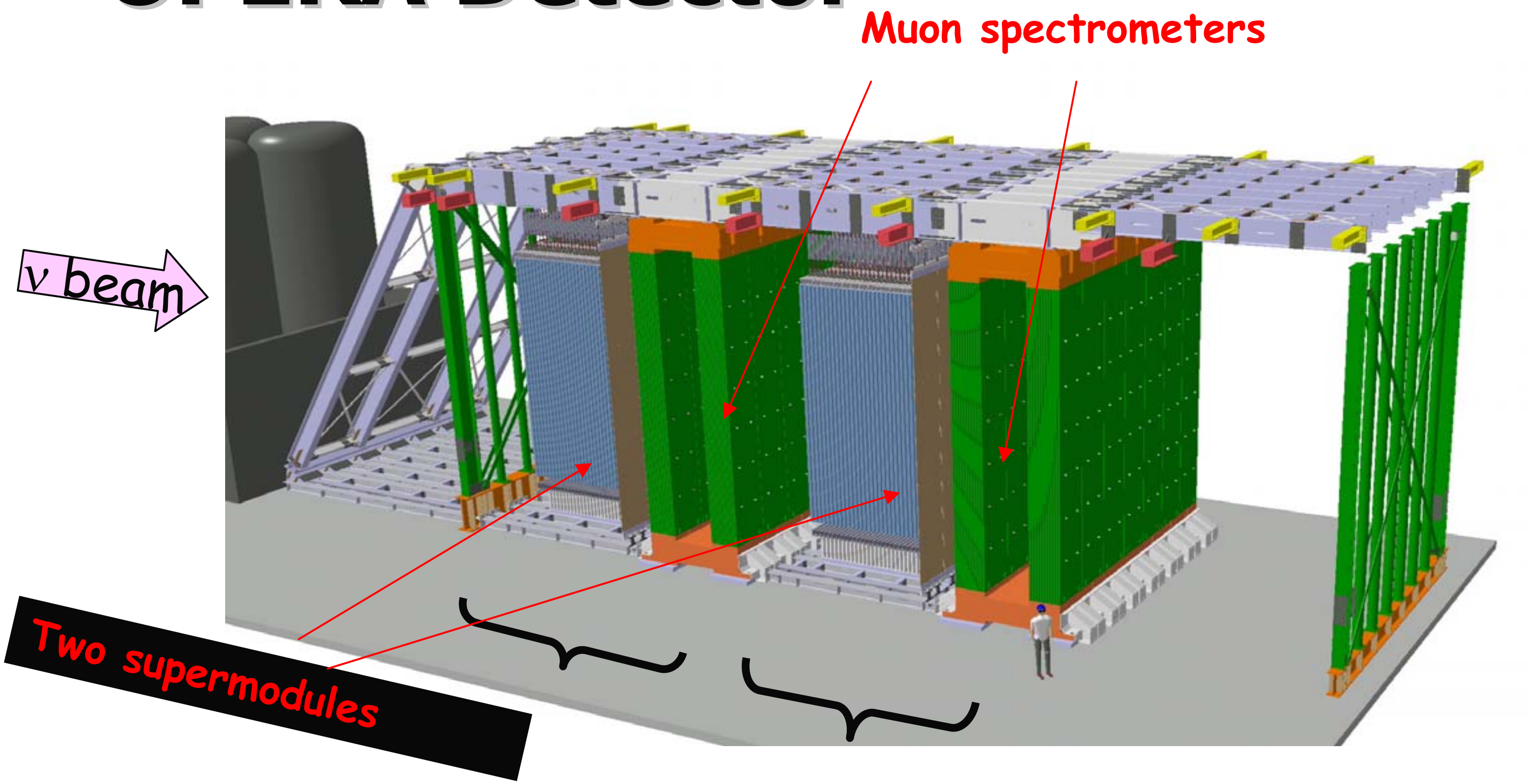
High energy, long baseline ν beam

($E_{CM} >> m_\tau$ L ~ 1000 km)



Average ν_μ energy ≈ 17 GeV
pure beam: 2% anti ν_μ <1% ν_e

OPERA Detector



Hybrid Detector:

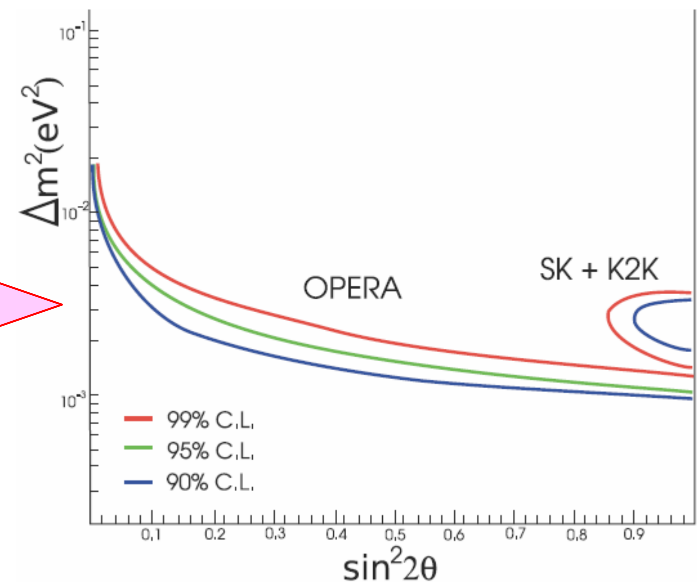
- Two supermodules – Target Mass 1766 tons
- 2 Magnetic spectrometers with RPC & Drift tubes
- 2 x [31 Target Tracker planes and Target Walls]
- 206,336 "ECC bricks" (56 Pb/Emulsion layers)
- 12 M Emulsion plates (thin double-coated)

OPERA: $\nu_\mu \rightarrow \nu_\tau$ sensitivity

full mixing, 5 years run at 4.5 x10^{19} pot / year

	signal (Δm^2=1.9x10^{-3}eV^2)	signal (Δm^2=2.4 x10^{-3}eV^2)	signal (Δm^2=3.0x10^{-3}eV^2)	BGD
OPERA 1.8 kton fiducial	6.6	10.5	16.4	0.7
+ brick finding + 3 prong decay	8.0	12.8	19.9	0.8-1.0

If OPERA does not observe τ candidates



OPERA: status and plan

First Beam → **August 2006**

7.6×10^{17} POT

October 2006

0.6×10^{17} POT

(water leak in reflector)
Electronic detectors only
no Pb/emulsion blocks

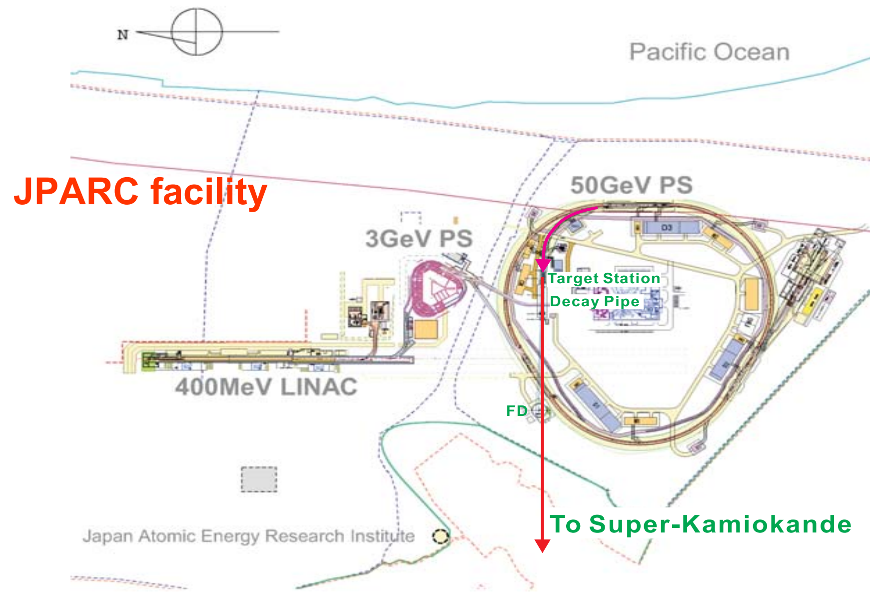
September-October 2007

expected $(1.2\text{-}1.6) \times 10^{19}$ POT

(reflector/horn repair)

Oscillation physics run **2008**

T2K (Tokai to Kamioka)

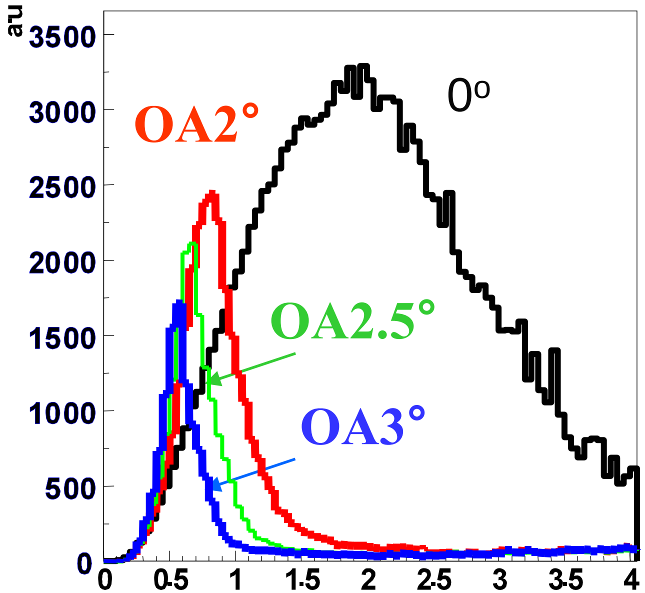


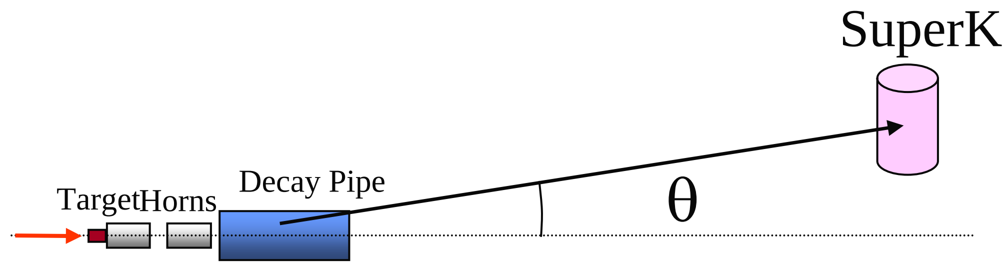
ν beam off-axis on-axis

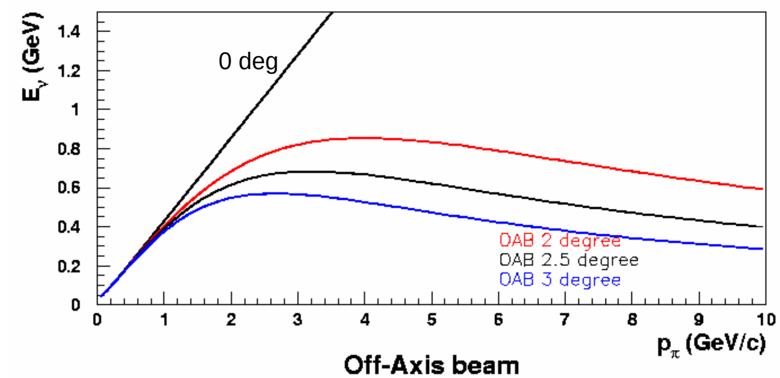
	JPARC	MINOS	Opera	K2K
E(GeV)	50	120	400	12
Int(10^{12} ppp)	330	40	24	6
Rate (Hz)	0.29	0.53	0.17	0.45
Power (MW)	0.77	0.41	0.5	0.0052

~1GeV ν_μ beam (×100 of K2K)

Off-axis Beam







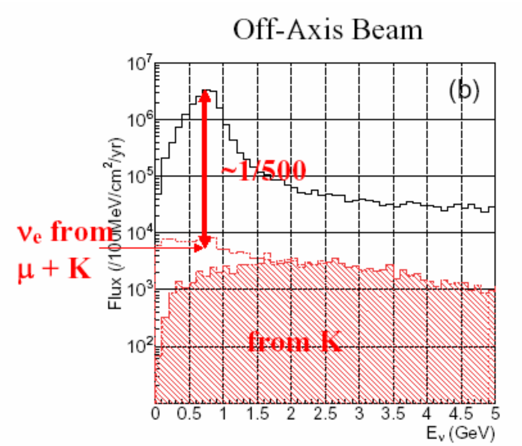
Statistics at SK

OAB 2.5 deg, 1 yr = 10^{21} POT, 22.5 kt

~ 2200 ν_μ tot

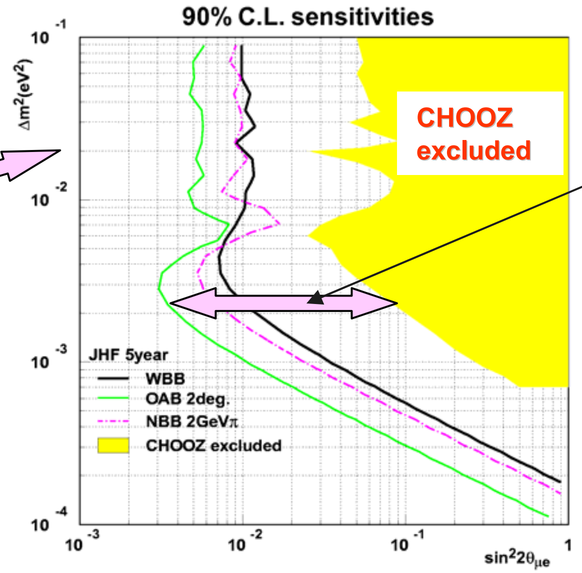
~ 1600 ν_μ charged current

ν_e < 0.5% at ν_μ peak



Intrinsic background: ν_e / ν_μ (peak) ~ 0.002

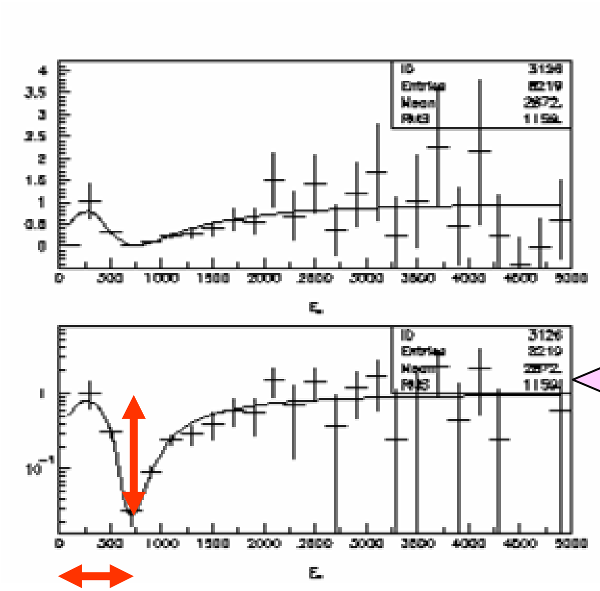
Principle Goals of T2K



Improvement by 20 times

- Search for ν_e appearance

θ_{13} sensitivity $\leq 1^o$ (90% c.l.)



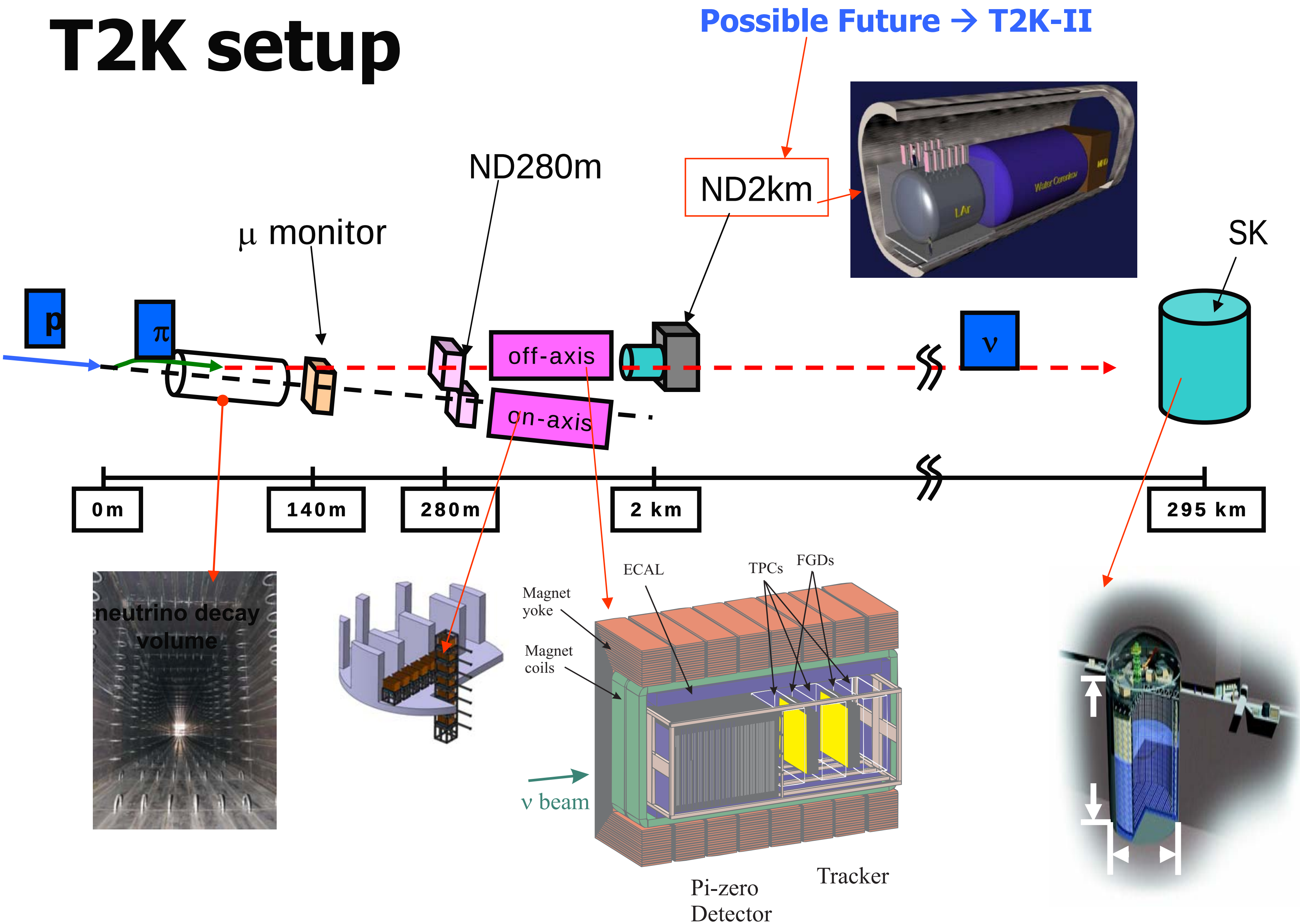
Measurement Δm^2_{23} with accuracy of 1%

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

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

- Confirmation of $\nu_\mu \rightarrow \nu_\tau$ oscillation

T2K setup


Possible Future → T2K-II
ND280m
ND2km
μ monitor
SK
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
Pi-zero Detector
Tracker

Заключение

MiniBOONE → - **осцилляций с $\Delta m^2 \sim 1$ eV^2 не обнаружено**
- **набор статистики с антинейтрино**

MINOS → - **подтверждение результатов SK и K2K**

OPERA → - **набор статистики начнется в 2008**

T2K-I → - **нейтринный пучок в 2009**