Status of the Double Chooz Experiment

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- Physics
- Experiment
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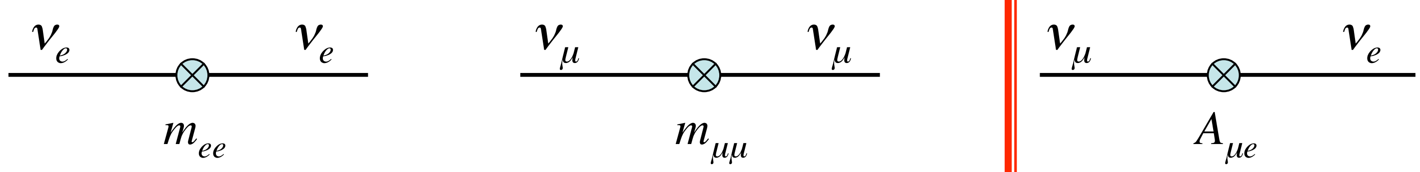
of Double Chooz

ν Oscillation

Charged lepton ≡ mass eigenstate
Simplified view.

Transition amplitudes



$\otimes$ = Flavor transition ampltude
- Higgs,
- Sub-structure?
- ...?

ν equation of motion:

$$i\frac{d}{dt}\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix}=\begin{pmatrix}m_{ee} & A_{\mu e}\\ A_{\mu e} & m_{\mu\mu}\end{pmatrix}\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix}$$

Definition of mass eigenstate

$$\begin{pmatrix}\nu_1\\ \nu_2\end{pmatrix}=\begin{pmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}\nu_e\\ \nu_\mu\end{pmatrix},\quad i\frac{d}{dt}\begin{pmatrix}\nu_1\\ \nu_2\end{pmatrix}=\begin{pmatrix}m_1\nu_1\\ m_2\nu_2\end{pmatrix}$$

ν Oscillation takes place

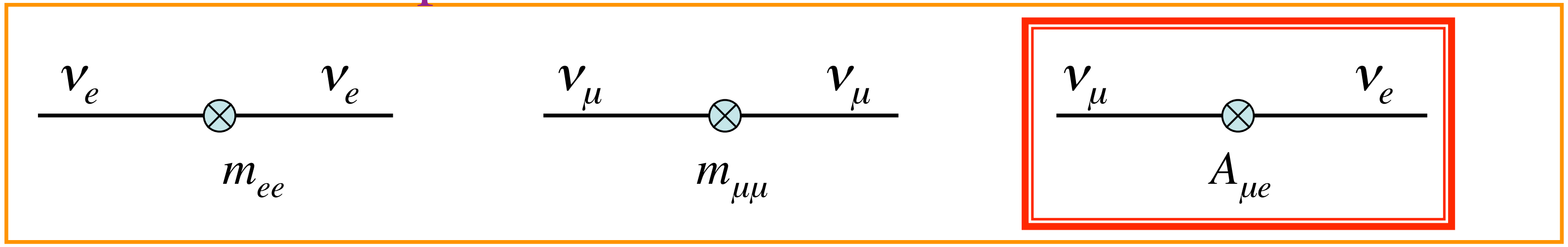
$(m_1, m_2 << E)$

$$P_{\nu_e\rightarrow\nu_\mu}=\sin^2 2\theta\sin^2\frac{\left(m_2^2-m_1^2\right)L}{4E}$$

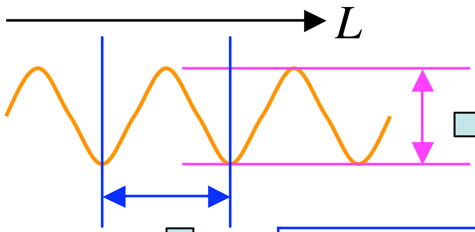
What We Measure by ν Oscillation

Charged lepton ≡ mass eigenstate
Simplified view.

Transition amplitudes



$$P_{\nu_e \to \nu_\mu} = \sin^2 2\theta \sin^2 \frac{(m_2^2 - m_1^2)L}{4E}$$

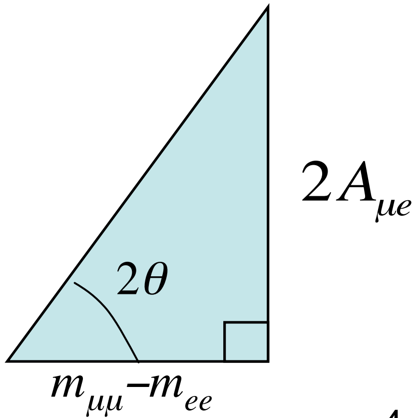


Amplitude ==> $\sin^2 2\theta$

Wavelength ==> $\Delta m^2 = |m_2^2 - m_1^2|$

What we measure through oscillation parameters

$$\tan 2\theta = \frac{2A_{\mu e}}{m_{\mu\mu} - m_{ee}}, \quad \Delta m_{12}^2 = \frac{|m_{\mu\mu}^2 - m_{ee}^2|}{\cos 2\theta}$$



ν Oscillations: 3 flavors

Mixings

MNS Matrix

$s_{ij} = \sin\theta_{ij}, \quad c_{ij} = \cos\theta_{ij}$

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

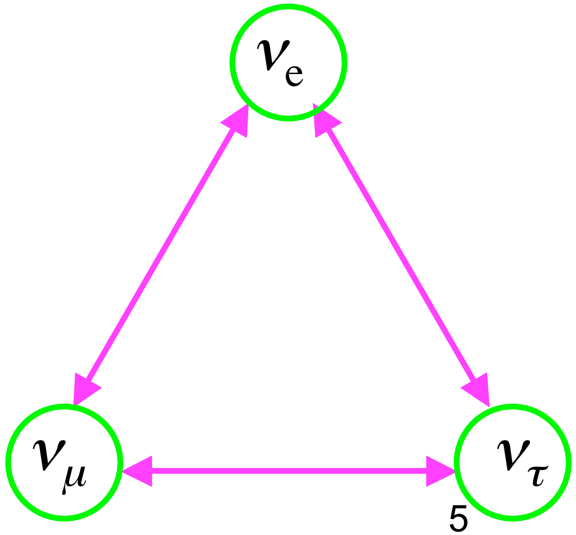
Oscillations

$$\begin{matrix} P(\nu_\alpha \to \nu_\beta) \\ P(\bar{\nu}_\alpha \to \bar{\nu}_\beta) \end{matrix} = \delta_{\alpha\beta} - 4\sum_{i>j} \mathrm{Re}\left(U_{\alpha i}^* U_{\beta i} U_{\alpha j} U_{\beta j}^*\right)\sin^2\Phi_{ij} \mp 2\sum_{i>j} \mathrm{Im}\left(U_{\alpha i}^* U_{\beta i} U_{\alpha j} U_{\beta j}^*\right)\sin 2\Phi_{ij}$$

$$\left(\Phi_{ij} = \frac{\Delta m_{ij}^2 L}{4E}, \quad \Delta m_{ij}^2 = m_j^2 - m_i^2\right)$$

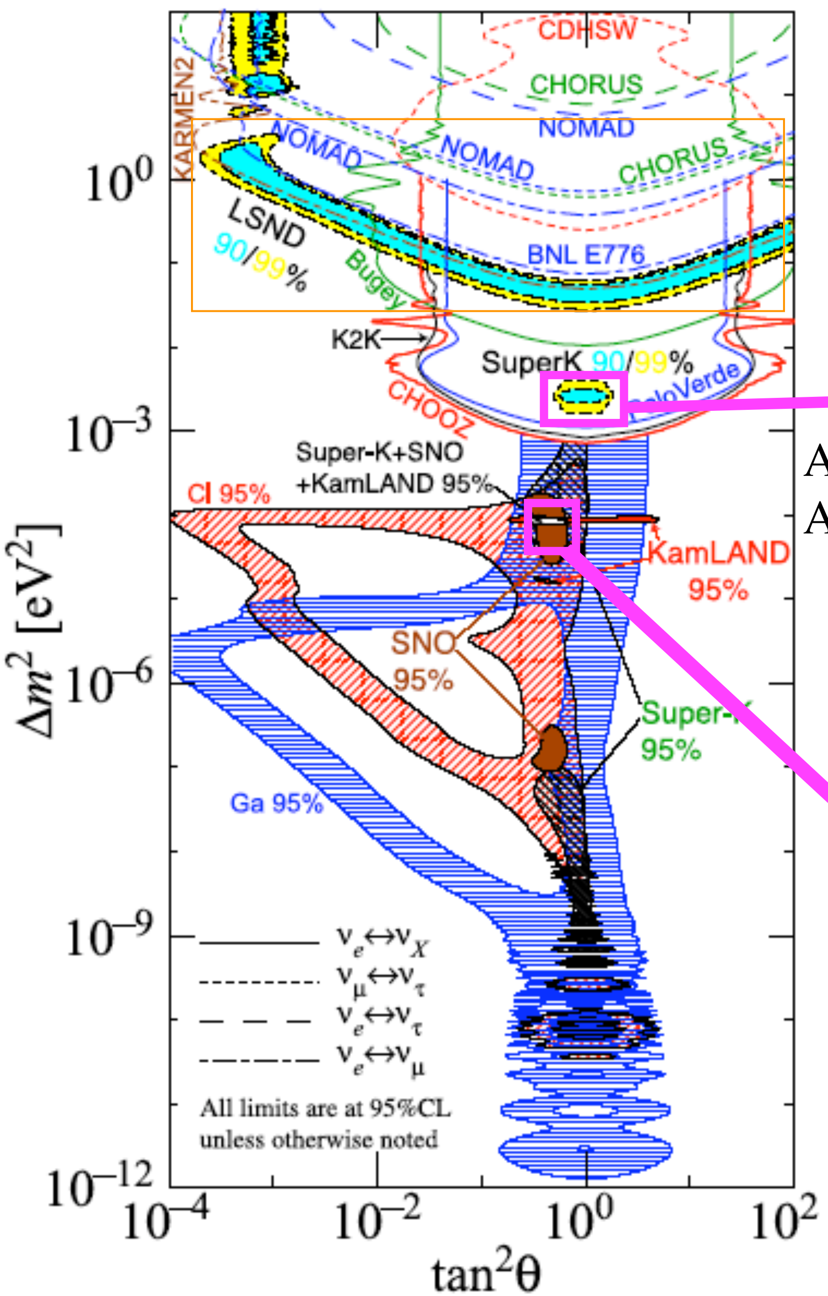
$$\left|\Delta m_{12}^2\right|, \quad \left|\Delta m_{23}^2\right|, \quad \theta_{12}, \quad \theta_{23}, \quad \theta_{31}, \quad \delta$$

6 parameters can be accessible from neutrino oscillation.

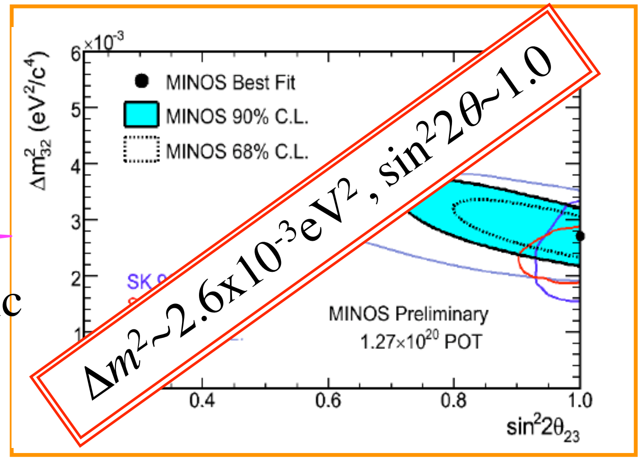


Murayama

Two oscillations measured

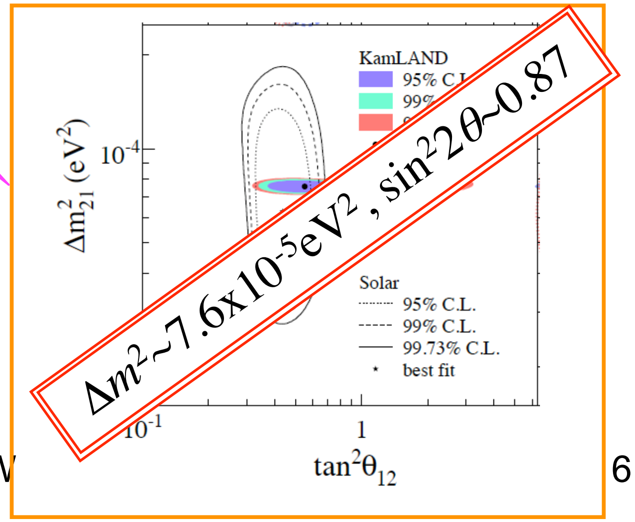


Atmospheric
Accelerator



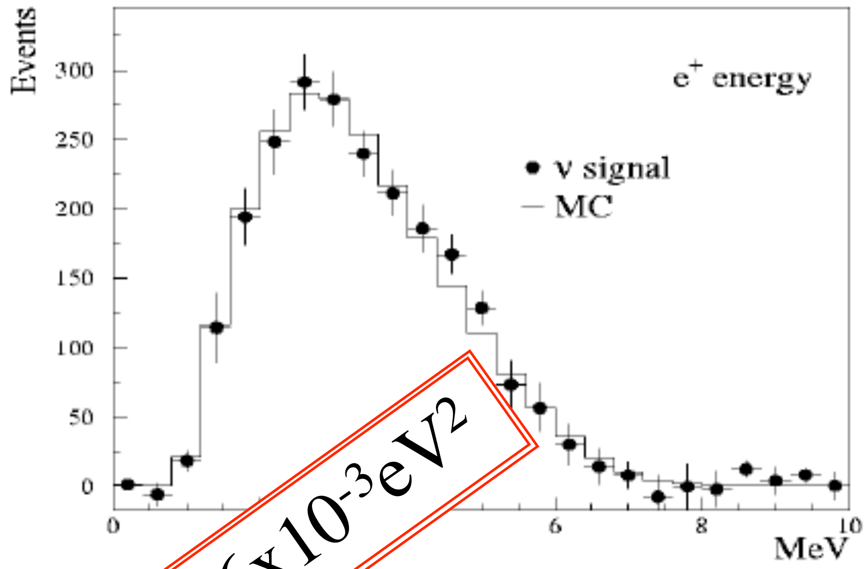
4/6 parameters were measured

Solar
Reactor

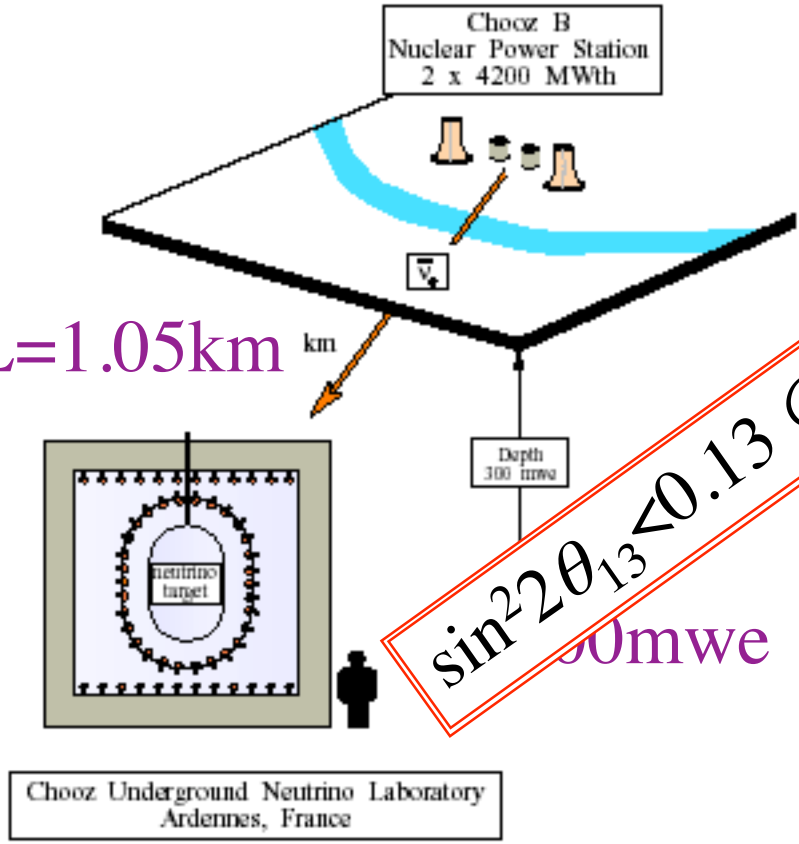


Upper limit on θ_{13}

CHOOZ reactor ($\overline{\nu}_e$ --> $\overline{\nu}_e$) experiment

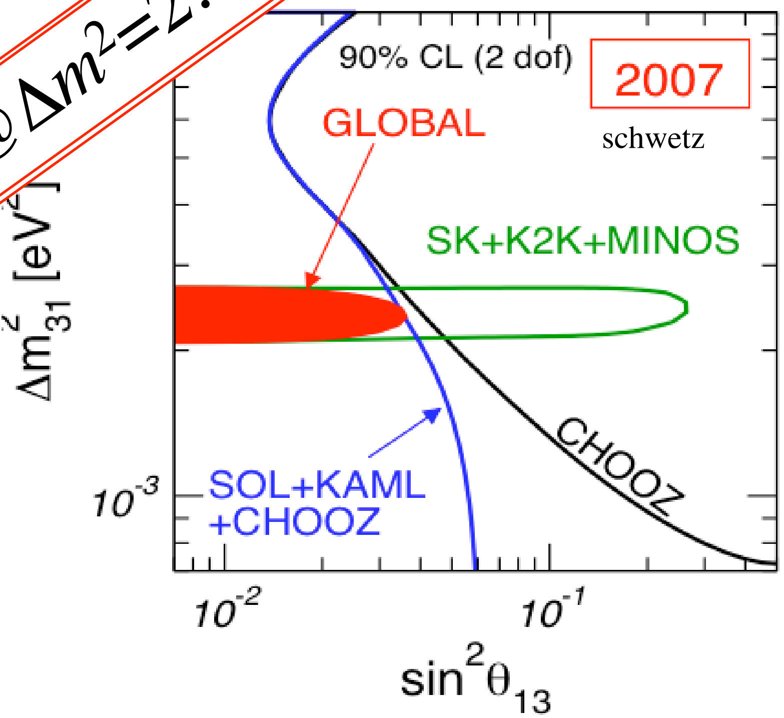


L=1.05km



$\sin^2 2\theta_{13} < 0.13$ @$\Delta m^2 = 2.6\times10^{-3}\,eV^2$

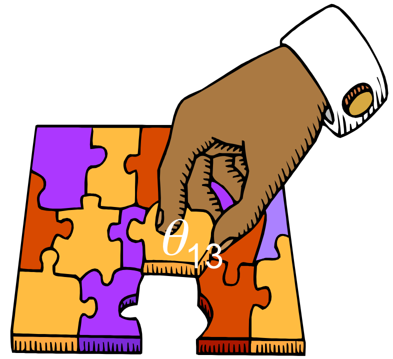
300mwe



Our Current Knowledge

$$\left|m_3^2 - m_2^2\right| \sim 2.6\times10^{-3}\,\mathrm{eV}^2,\quad \left(m_2^2 - m_1^2\right) \sim 8.0\times10^{-5}\,\mathrm{eV}^2$$

$$U_{MNS} \sim \begin{pmatrix} 0.8 & 0.5 & s_{13}e^{i\delta} \\ -0.4 & 0.6 & 0.7 \\ 0.4 & -0.6 & 0.7 \end{pmatrix} \quad \left|s_{13}\right| < 0.2$$



Transition Amplitudes, if $m_1 << m_2 < m_3$

ν_e — ν_e: m_{ee}~5meV

ν_μ — ν_μ: $m_{\mu\mu}$~30meV

ν_τ — ν_τ: $m_{\tau\tau}$~30meV

ν_e — ν_μ: $A_{e\mu}$~$(30s_{13}e^{i\delta}+3)$meV

ν_e — ν_τ: $A_{e\tau}$~$(30s_{13}e^{i\delta}-3)$meV

ν_μ — ν_τ: $A_{\mu\tau}$~20meV

θ_{13} controls size of imaginary part of ν_e <=> ν_μ, ν_τ
=> Measurement is important to complete the puzzle

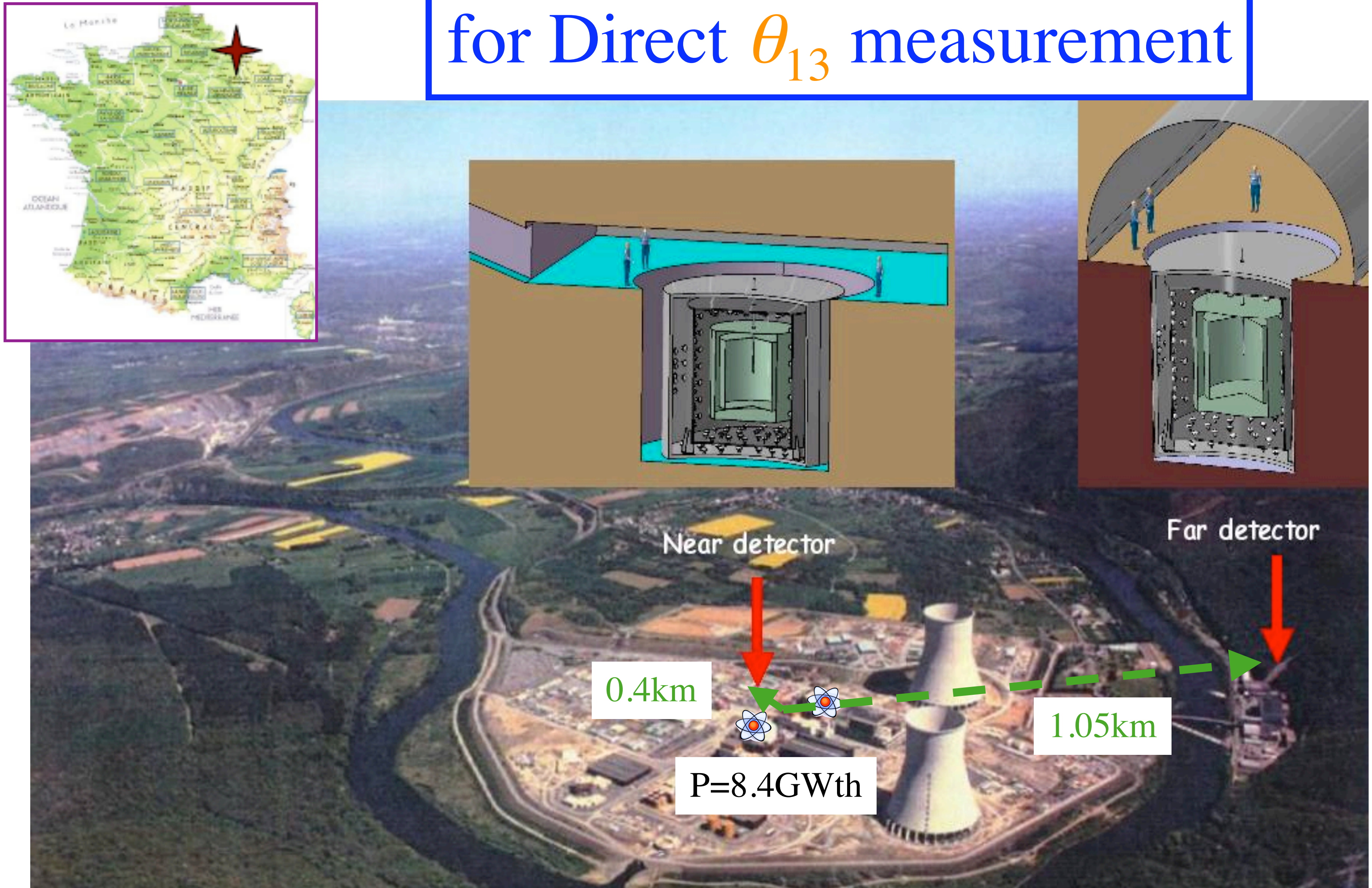
Remaining Subjects of ν Oscillation Studies

subject	Method
θ_{13}	$[\nu_\mu \to \nu_e]_A \sim \sin^2\theta_{23}\underline{\sin^2 2\theta_{13}} \mp 0.05 \cdot \sin\theta_{13}\sin\delta$ $[\bar{\nu}_e \to \bar{\nu}_e]_R = 1 - \underline{\sin^2 2\theta_{13}}$ ← This is the only pure measruement.
δ	$[\nu_\mu \to \nu_e]_A - [\bar{\nu}_\mu \to \bar{\nu}_e]_A \sim \underline{\sin 2\theta_{13}}\sin\delta$
θ_{23} degeneracy $\sin\theta_{23} = \frac{1 \pm \sqrt{1-\sin^2 2\theta_{23}}}{2}$	$[\nu_\mu \to \nu_e]_A + [\nu_\mu \to \nu_e]_A \sim \sin^2\theta_{23}\underline{\sin^2 2\theta_{13}}$
mass hierarchy ($m_2<m_3$ or $m_3<m_2$)	$[\nu_\mu \to \nu_e] - [\bar{\nu}_\mu \to \bar{\nu}_e]$ $\sim 0.00017 L[km] \cdot sign(\Delta m^2_{23})\underline{\sin^2 2\theta_{13}}$

θ_{13} is necessary to access all of these.

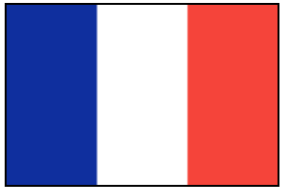
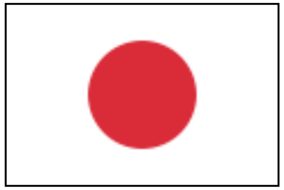
θ_{13} plays key roles. => Measurement is urgent.
And combination of accelerator and reactor exp. is importnat to solve all these ambiguities.

Double Chooz Experiment for Direct θ_{13} measurement



Compare the near and far detectors to cancel systematics

Double Chooz Collaboration

~150 people, 33 institutes, 8 countries

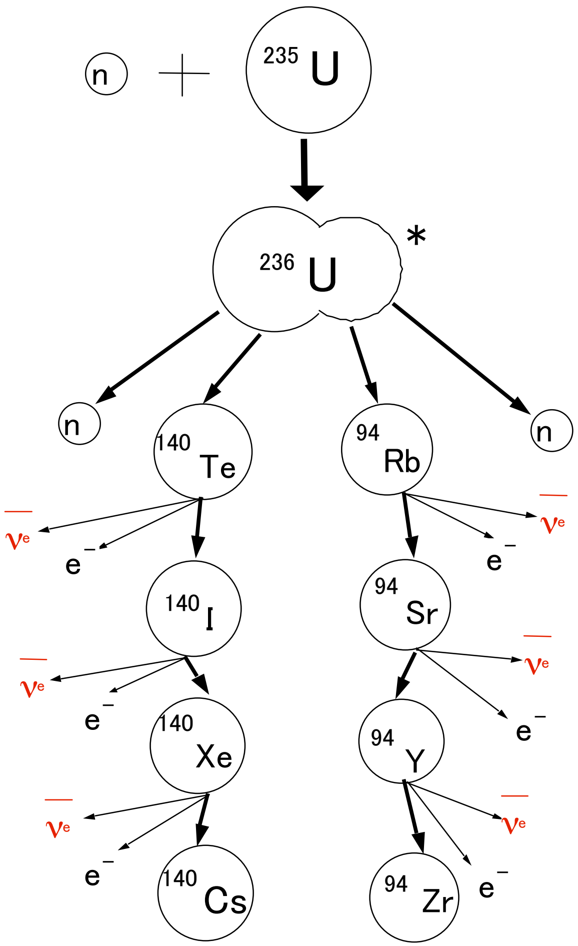
DC Collaboration meeting @ Kobe 2008.3.

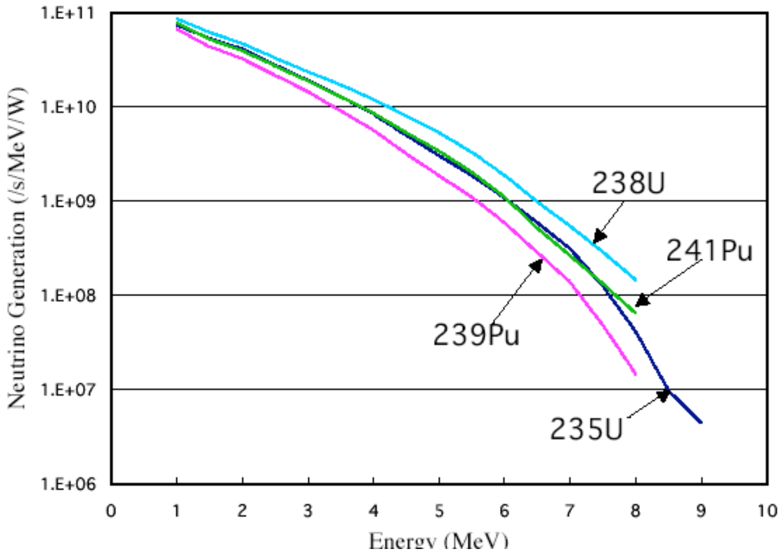
Collaboration

- Japan
  - Tohoku Univ.
  - Tokyo Metropolitan Univ.
  - Niigata Univ.
  - Tokyo Institut of Technology
  - Kobe Univ.
  - Tohoku Gakuin Univ.
  - Miyagi University of Education
  - Hiroshima Inst. of Technology
- USA
  - Livermore nat lab
  - Argonne
  - Columbia Univ
  - Chicago Univ
  - Kansas U
  - Notre Dame U
  - Tennesse U
  - Alabama U
  - Drexel U
  - Illinois Inst tech
- France
  - Saclay
  - APC (collège de France)
  - Subatech Nantes
- Germany
  - Max planck Heidelberg
  - Munich U
  - Hamburg U
  - Tubingen U
  - Aachen U
- Spain
  - CIEMAT Madrid
- England
  - Oxford
  - Sussex Univ
- Russia
  - Kurchatov inst
  - Sc. Acad.
- Brasil
  - CBPF
  - UNICAMP

Reactor Neutrino



Neutrino Spectra



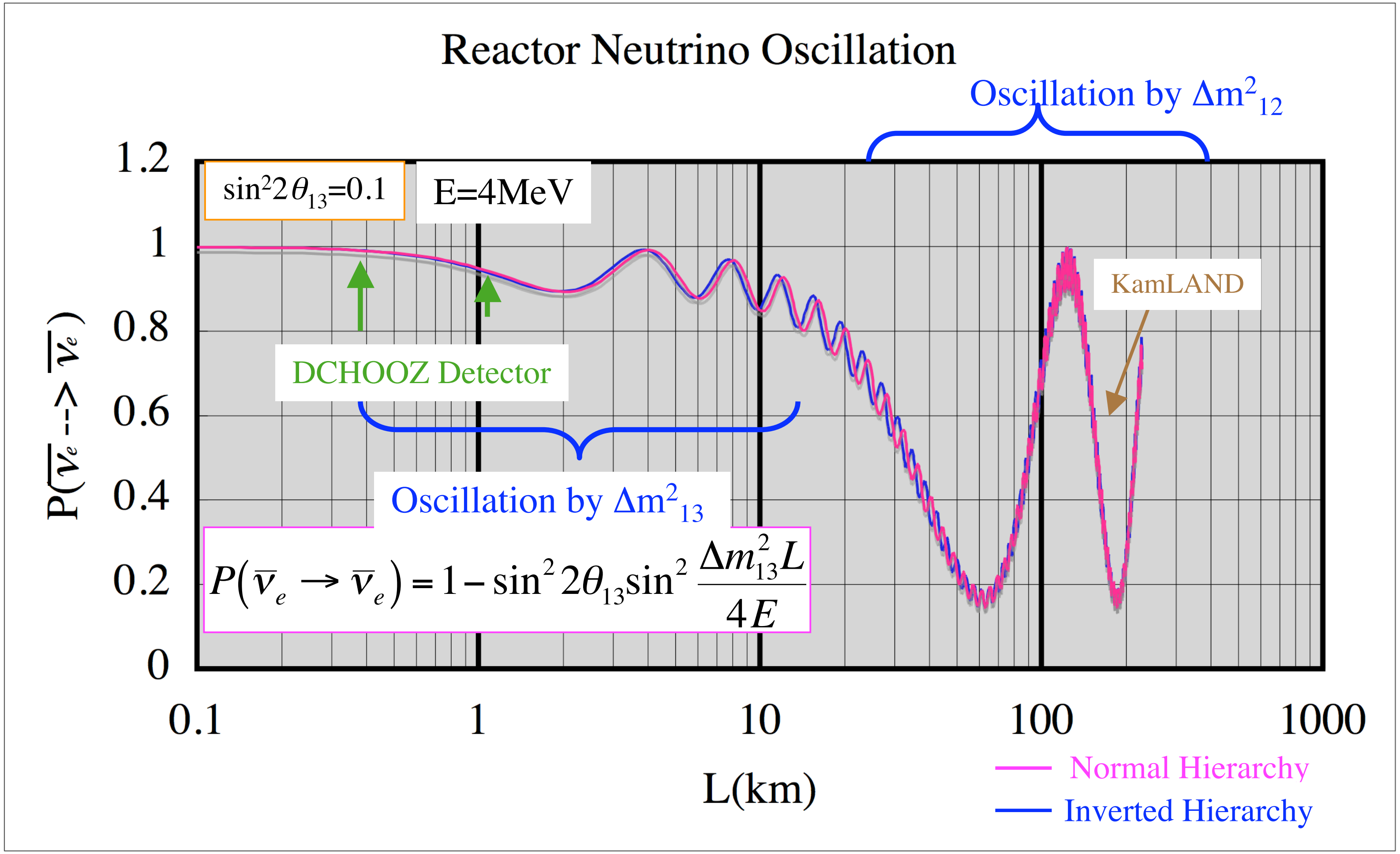
E_ν~ a few MeV: 10^{-3} of accelerator ν

~6ν/fission & ~200MeV/fission

$$\Downarrow$$

$$\sim 6\times10^{20}\,\bar{\nu}_e\,/\,s\,/\,reactor$$

Reactor θ_{13} measurement



Small deficit (=$\sin^2 2\theta_{13}$) ==> High Precision is necessary (δ<1%)

2004-2007: Detector design

Calibration Glove-Box :

Outer Veto :
Scintillator panels

Target ν : 10,3 m^3
LS; 80% $C_{12}H_{26}$+ 20% PXE +0,1% Gd + PPO + Bis-MSB

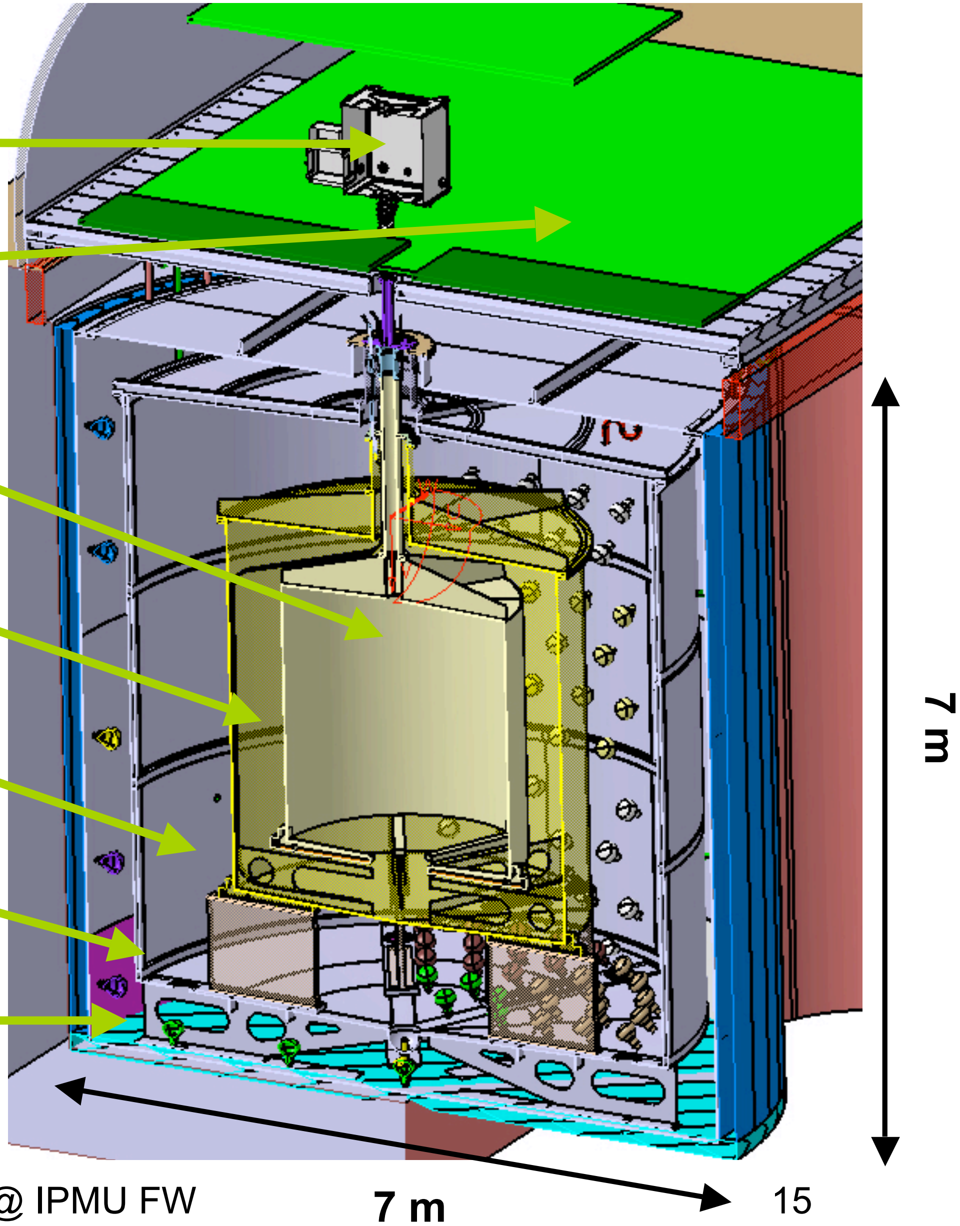
γ Catcher : 22,6 m^3
LS; 80% $C_{12}H_{26}$ + 20% PXE + PPO + Bis-MSB

Non scintillating Buffer : 114 m^3
mineral oil

Buffer vessel & 390 10'' PMTs :
Stainless steel 3 mm

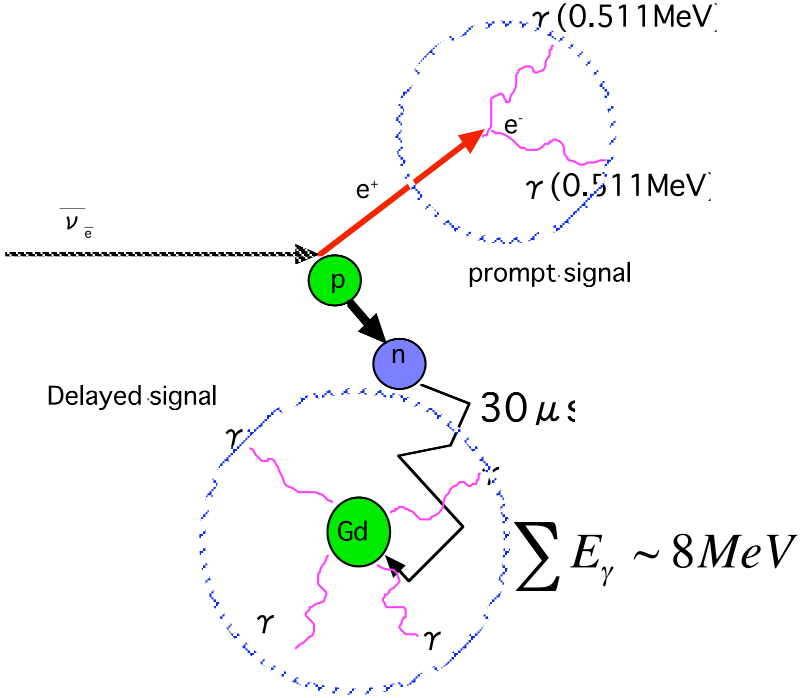
Inner Muon Veto : 90 m^3
mineral oil + 70 8'' PMTs

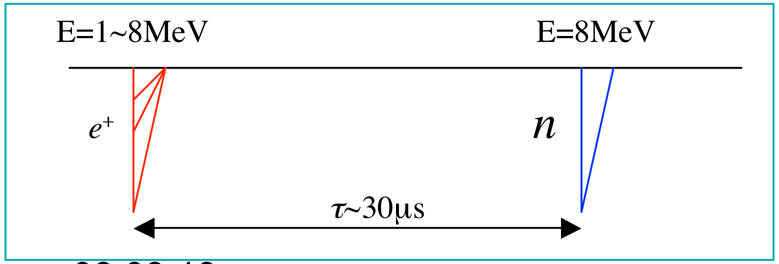
Steel Shielding :
17 cm steel, All around

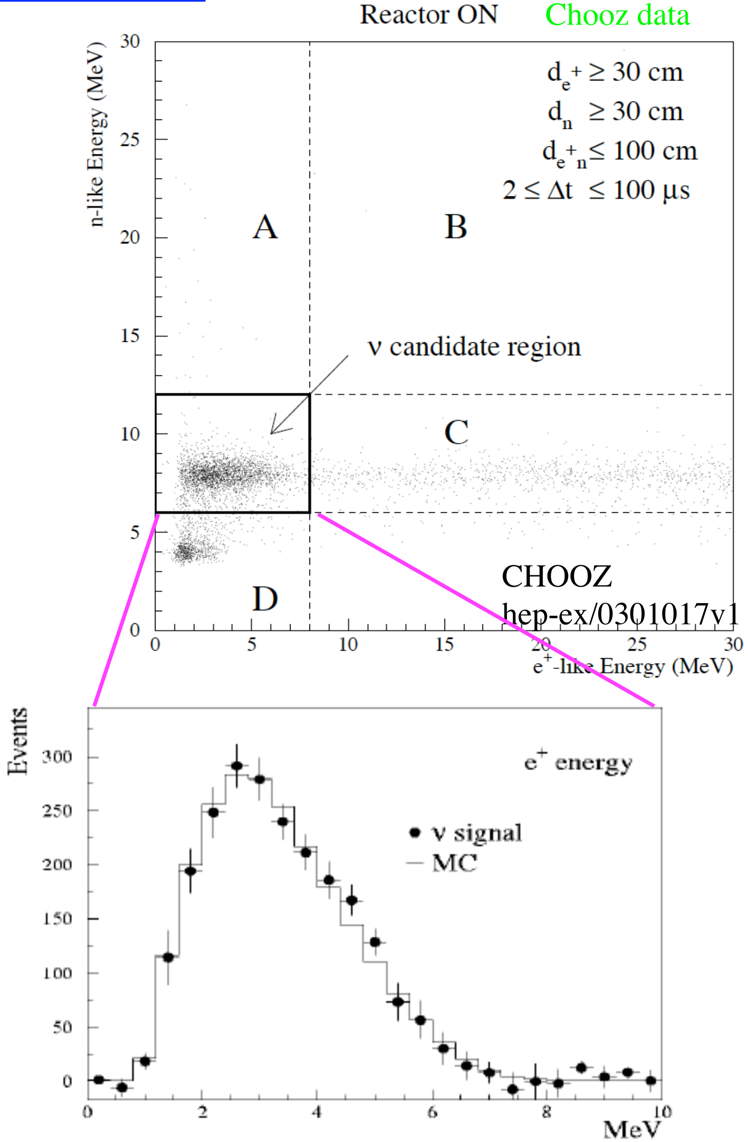


$\bar{\nu}_e$ Detection

Gd doped liquid scintillator

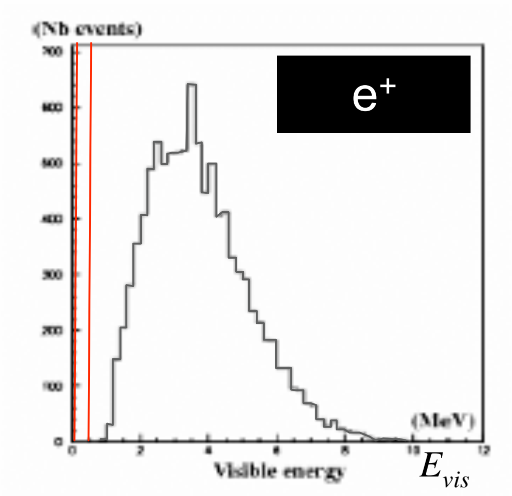


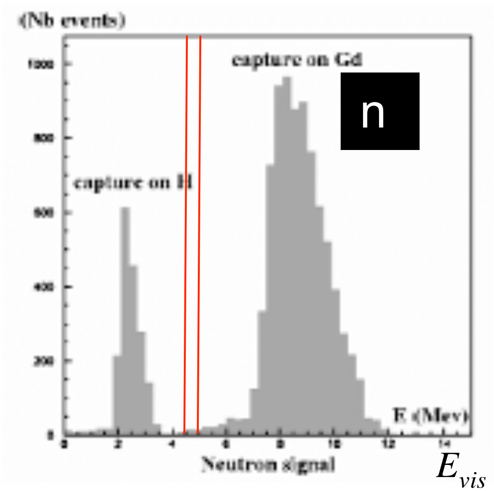


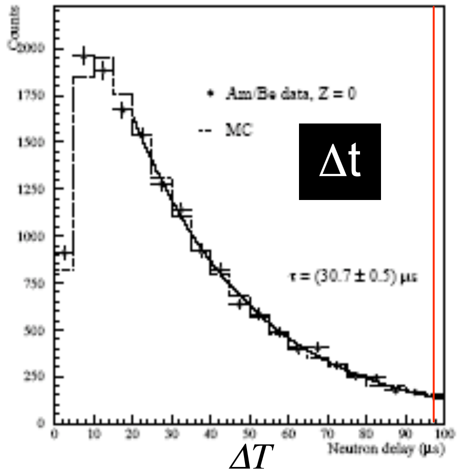


Improvement from CHOOZ

* Near/Far cancellations
* Efficiency is insensitive to the energy scale error
- No fiducial volume cuts
- Reduced Backbrounds

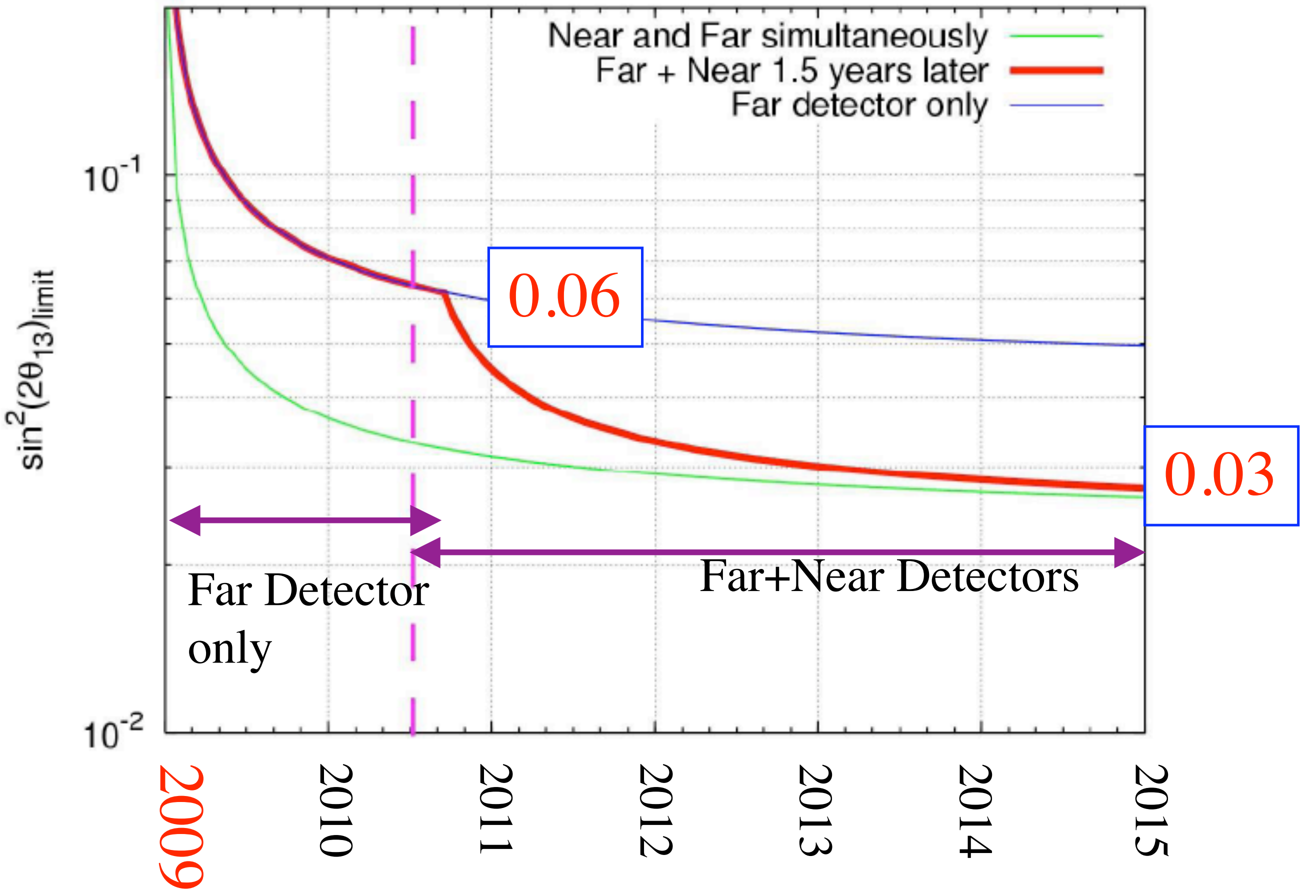






	CHOOZ	Double CHOOZ
Statistical Error:	2.7%	0.5%
Systematic Error	2.7%	<0.6%
Total error	3.8%	<0.8%
$d\sin^2 2\theta_{13}$(90%CL)	0.13	<0.03

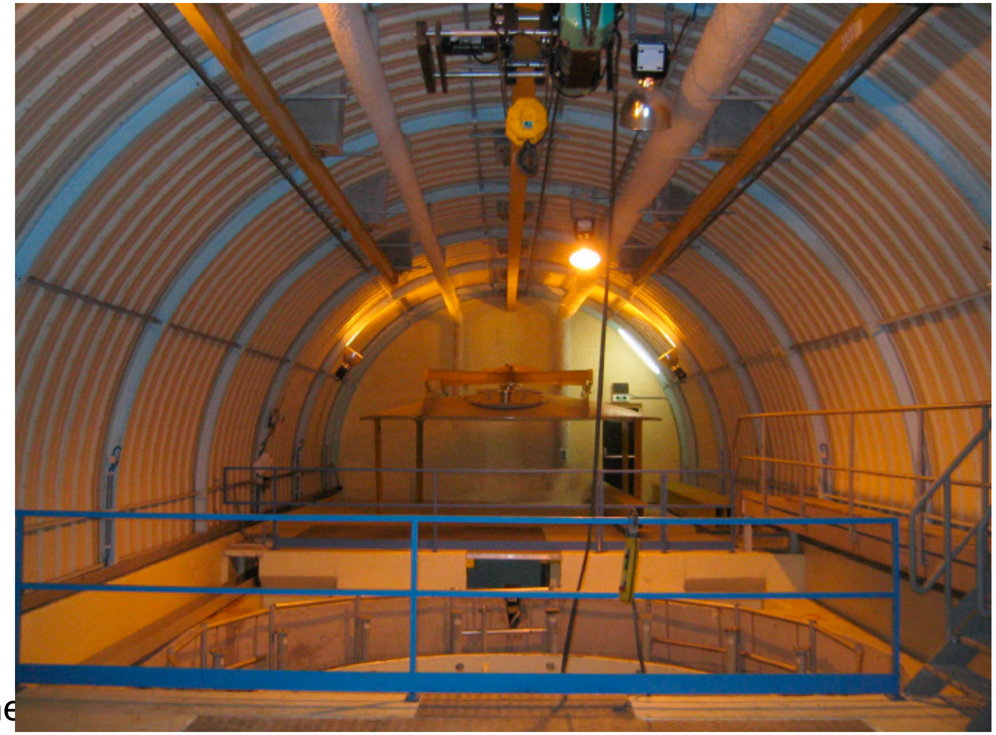
Sensitivity in time



Far Detector Experimental Hall

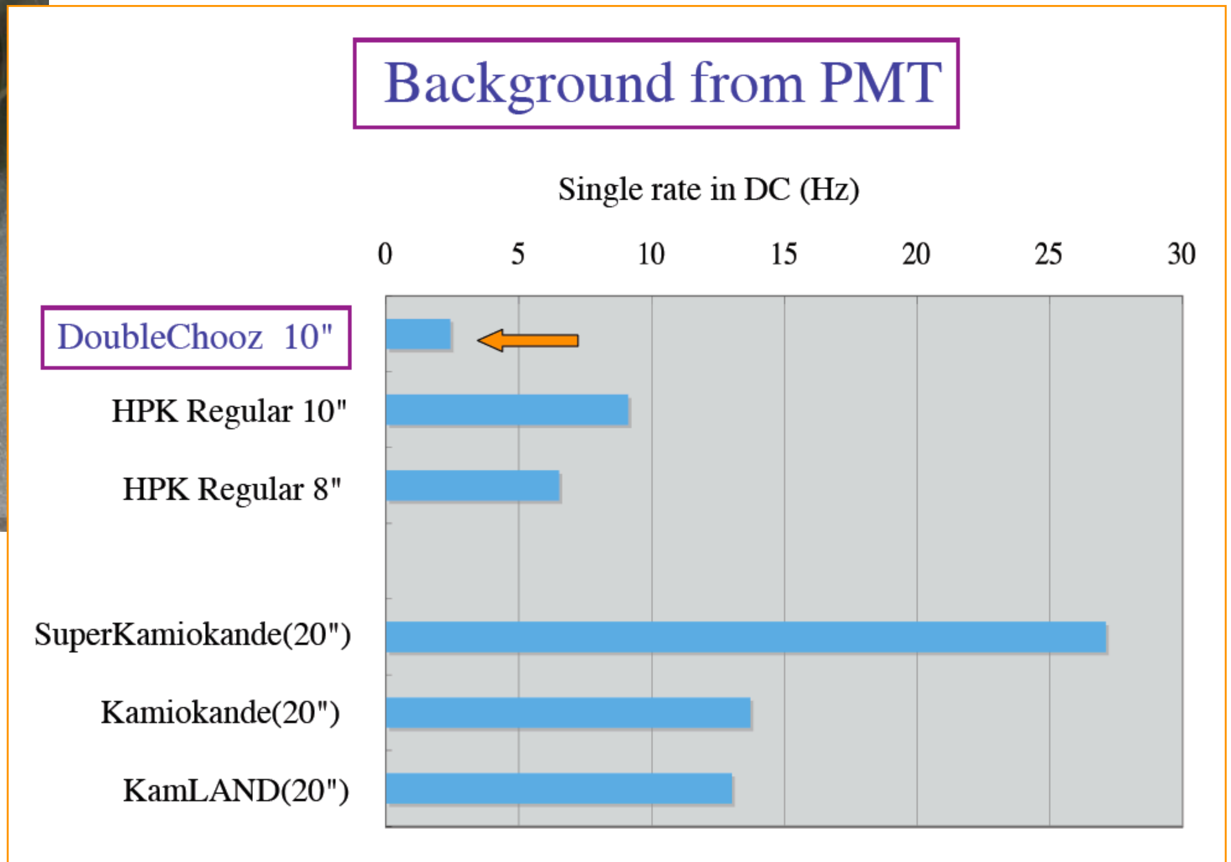
Already Exists

300mwe depth

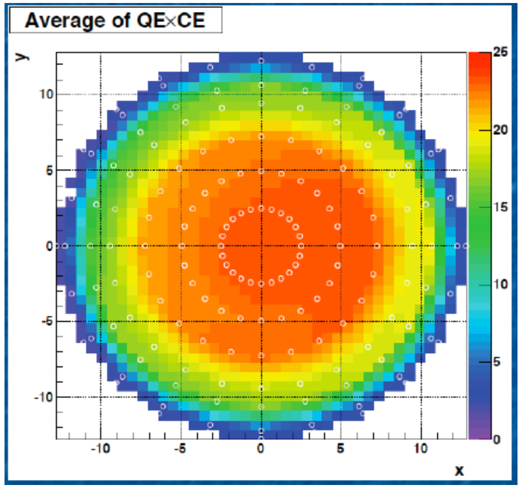


Large & Low background Photomultipliers

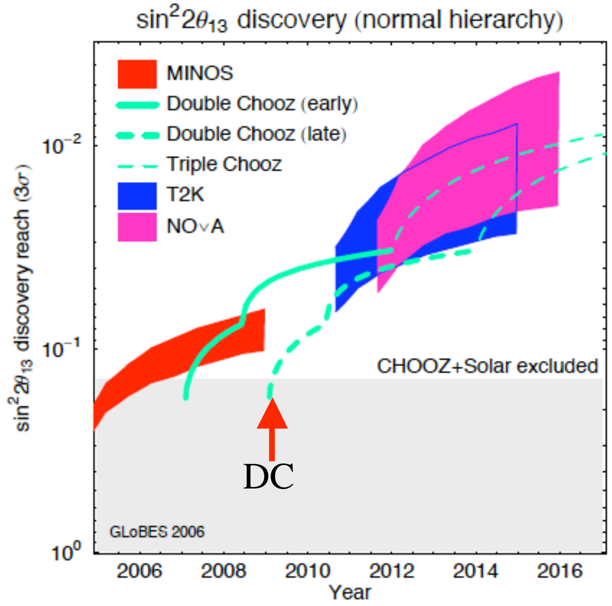
=> producing

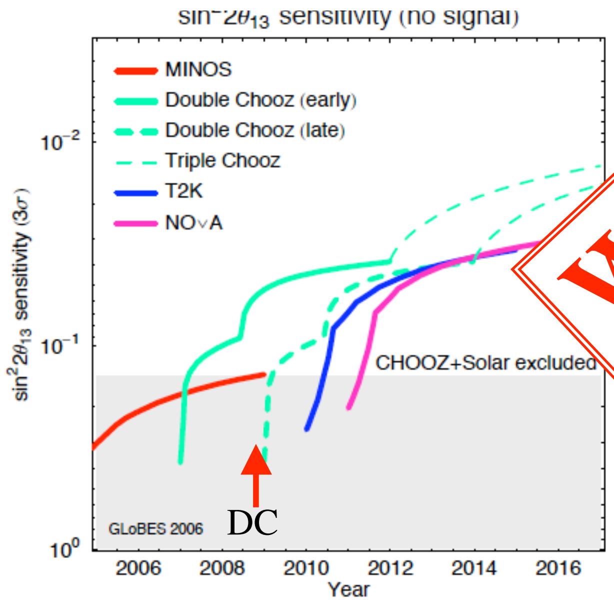


PMT test system ready



Prospects





If $\sin^2 2\theta_{13}$ is found >0.0

⇒There is a good c… measure CPV δ.

⇒We can go f… the next experiments

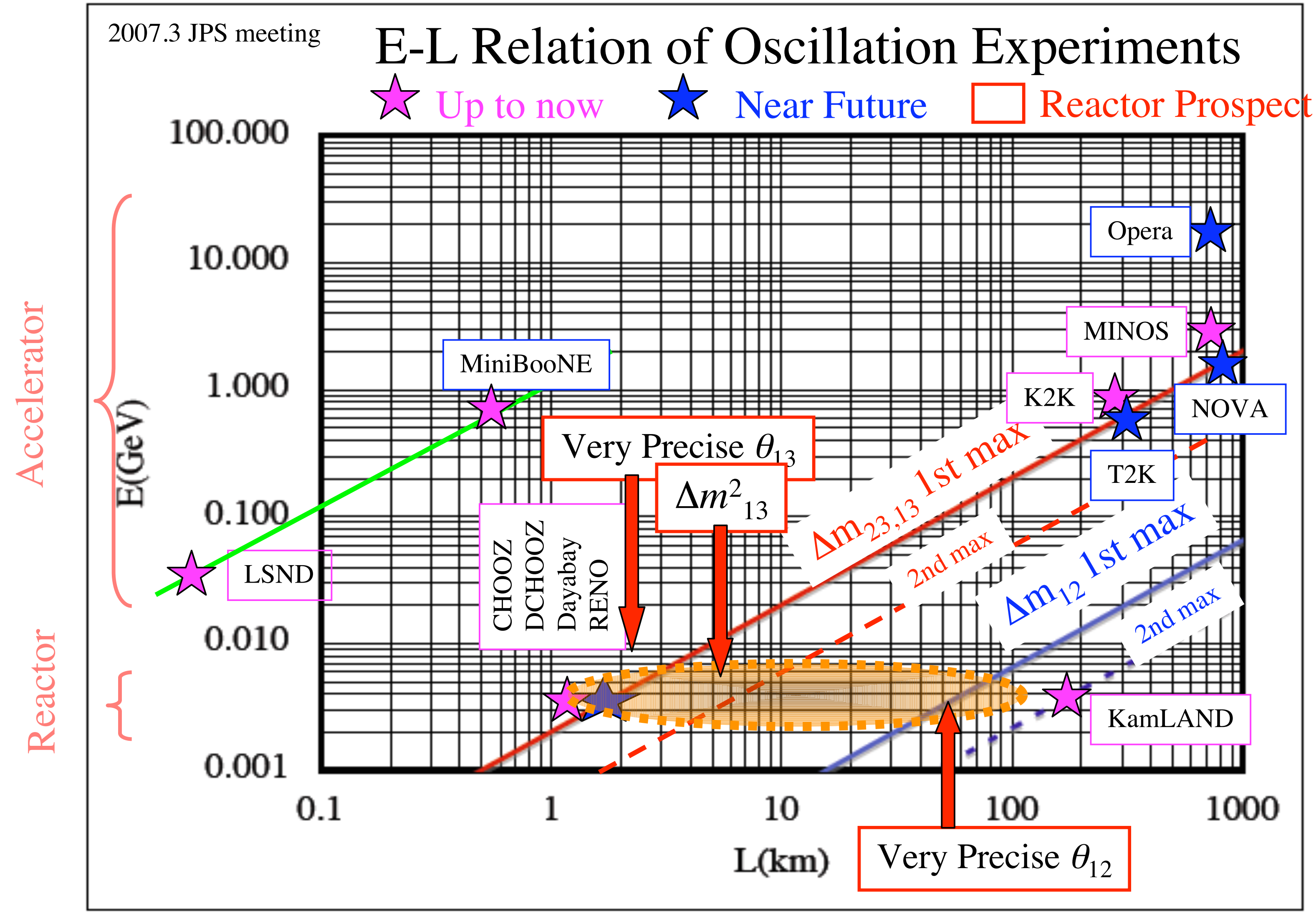
We will know which in 2~4yrs

…θ_{13} is found <0.03

…t is difficult to measure CPV δ.

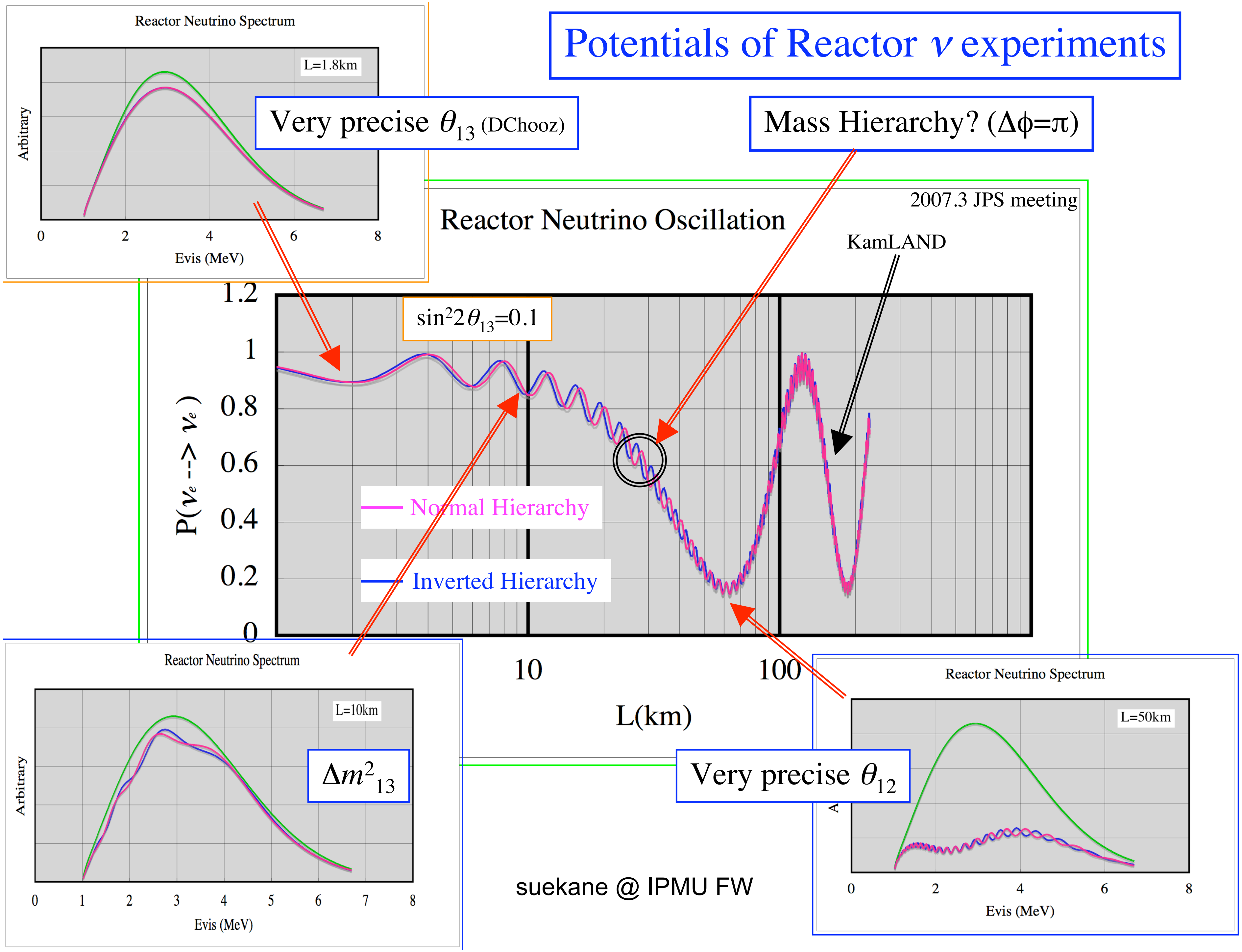
⇒It is necessary to re-think the future plan.

Potential of Reactor ν experiments



Many experiments are targeting Δm_{23} 1st oscillation maximum.
Why not Δm_{12} oscillation maximum??? Only reactor can do it!!

Potentials of Reactor ν experiments



suekane @ IPMU FW

Summary

- DoubleChooz is a reactor ν experiment to measure $\sin^2 2\theta_{13}$ with precision 0.03.
- Most of the detector R&D has been finished and the construction started.
- The first data taking is scheduled in 2009

* Reactor neutrino has various possibilities to measure the oscillation parameters by making use of its low energy and extremely high flux.