Reactor
Neutrino Experiments

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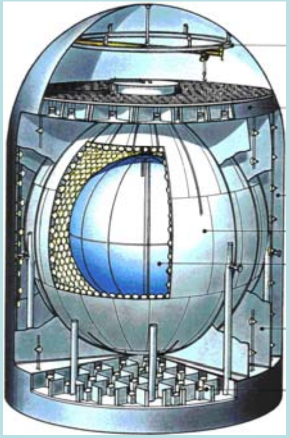


P5 meeting, SLAC, February 21, 2008

Pontecorvo - Maki - Nakagawa - Sakata Matrix

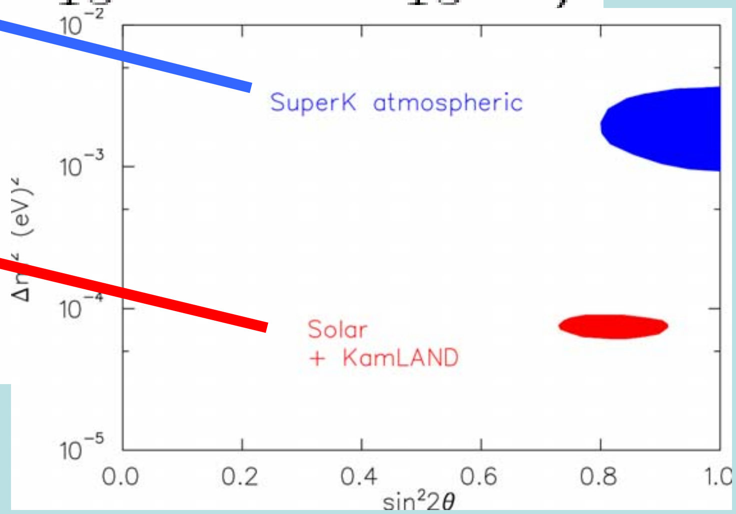
$$U_{\rm PMNS} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}$$

$$= \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix}$$

$$\times \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} .$$

Gateway to Leptonic CP Violation!

CP violation



$\overline{\nu}_e$ Survival Probability

$$P_{\rm sur} = 1 - C_{13}^4 \sin^2 2\theta_{12} \sin^2 \Delta_{21}$$

$$- C_{12}^2 \sin^2 2\theta_{13} \sin^2 \Delta_{31} - S_{12}^2 \sin^2 2\theta_{13} \sin^2 \Delta_{32}$$

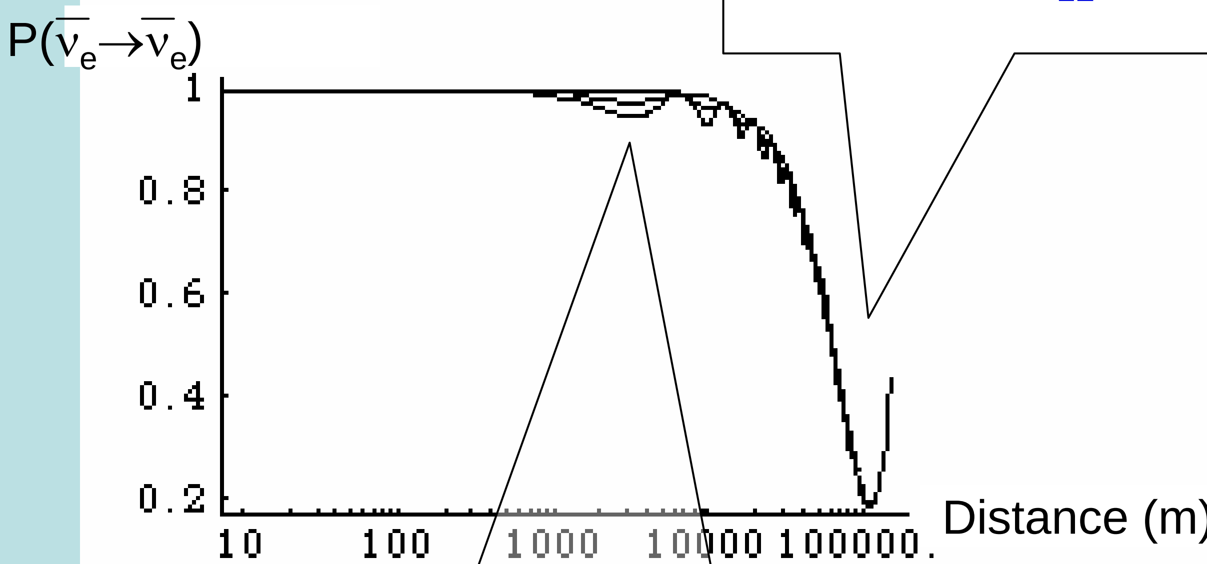
$$\Delta_{\rm jk} \equiv 1.267 \Delta m_{\rm jk}^2 ({\rm eV}^2) \times 10^3 \frac{L({\rm km})}{E({\rm MeV})}$$

$$\Delta m_{\rm jk}^2 \equiv m_{\rm j}^2 - m_{\rm k}^2$$

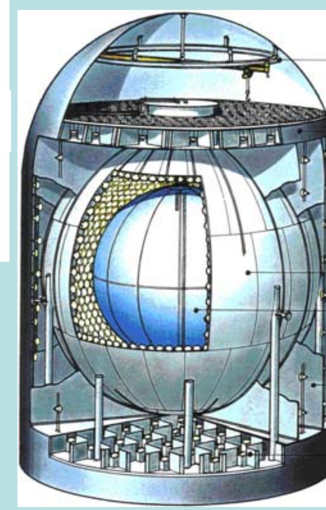
- “Clean” measurements of θ, Δm^2
- No CP violation
- Negligible matter effects

$\overline{\nu}_e$ Disappearance ($\theta_{13} << \theta_{12}$, $\Delta_{21} << |\Delta_{31}|$)

Dominant θ_{12} Oscillation

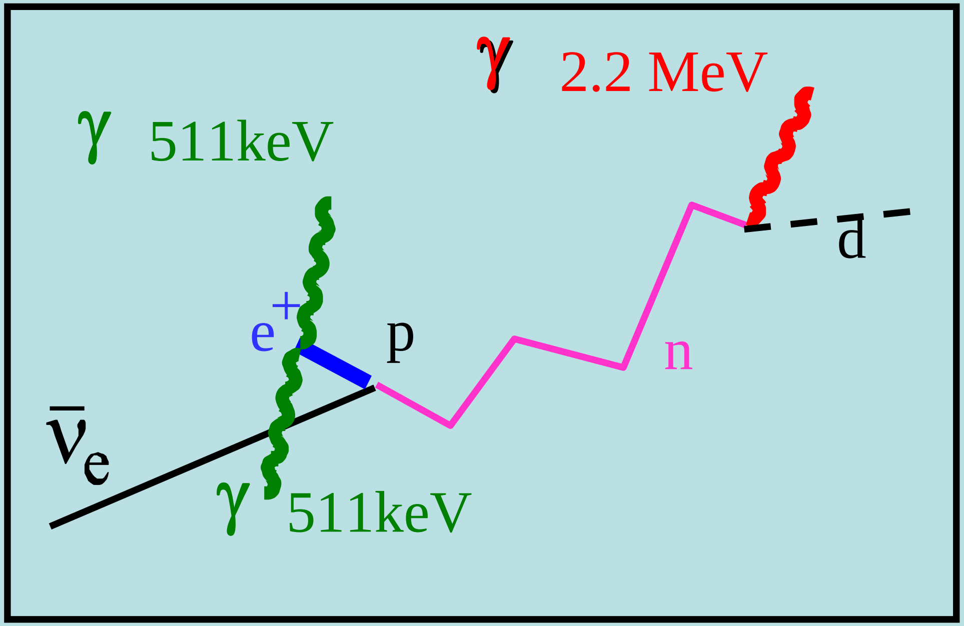


Subdominant θ_{13} Oscillation



Detection Signal

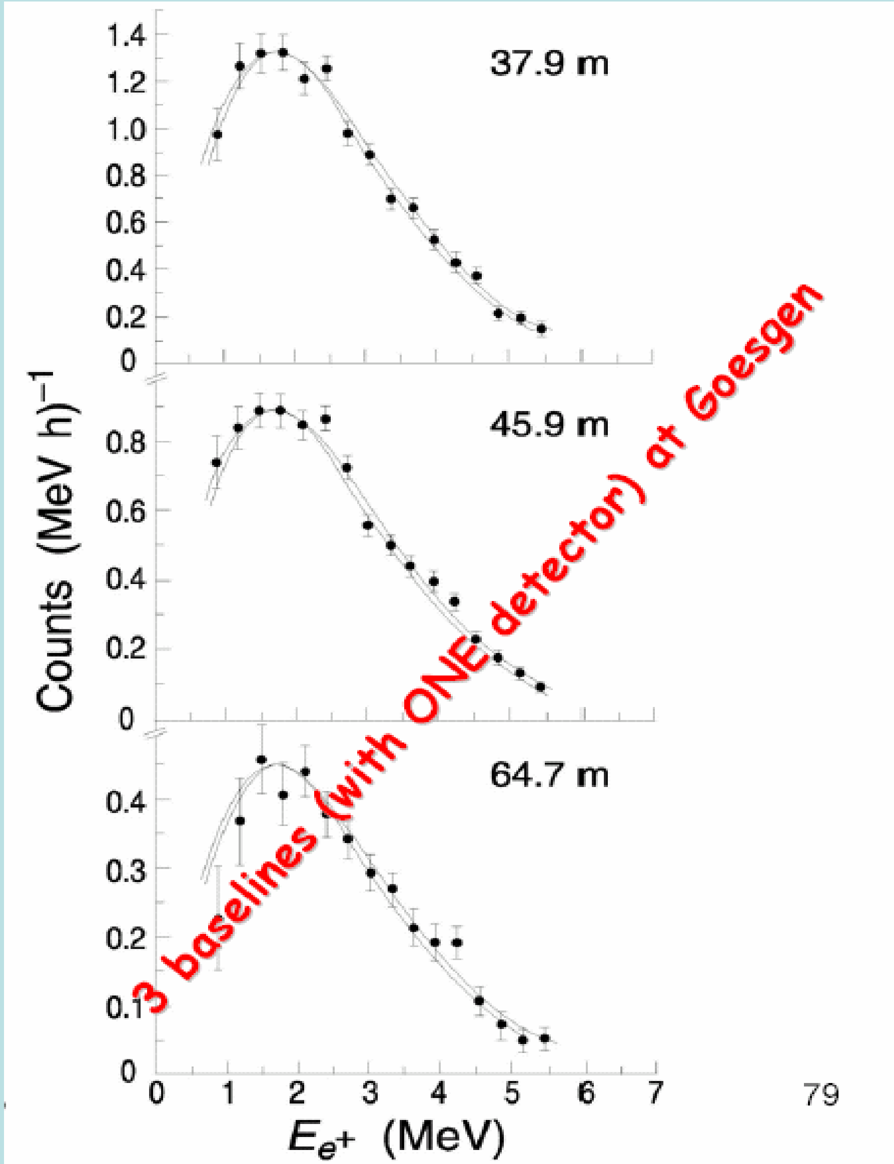
$\overline{\nu} + p \rightarrow n + e^{+}$

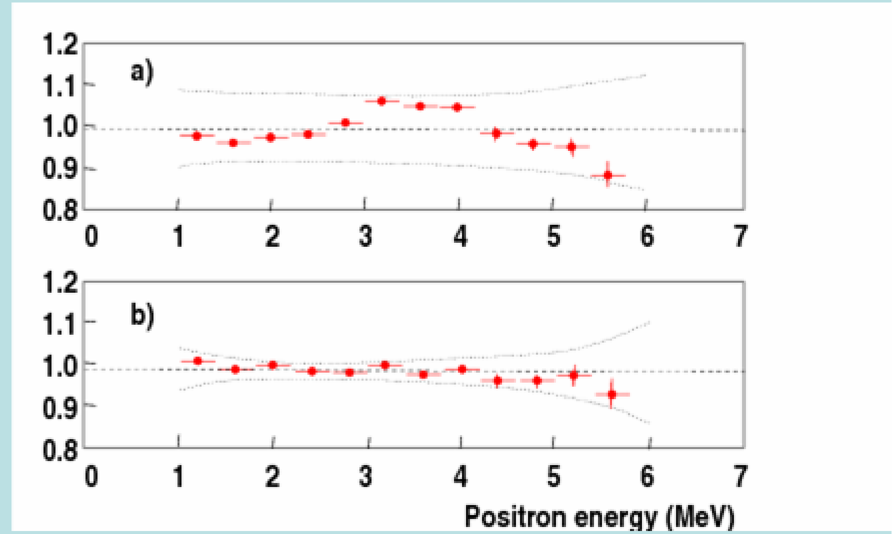


Coincidence signal:

- Prompt: e^{+} annihilation → $E_{\nu} = E_{prompt} + \overline{E}_{n} + 0.8$ MeV
- Delayed: **n+p** 180 μs capture time, 2.2 MeV
  n+Gd 30 μs capture time, 8 MeV

Early Experimental Results

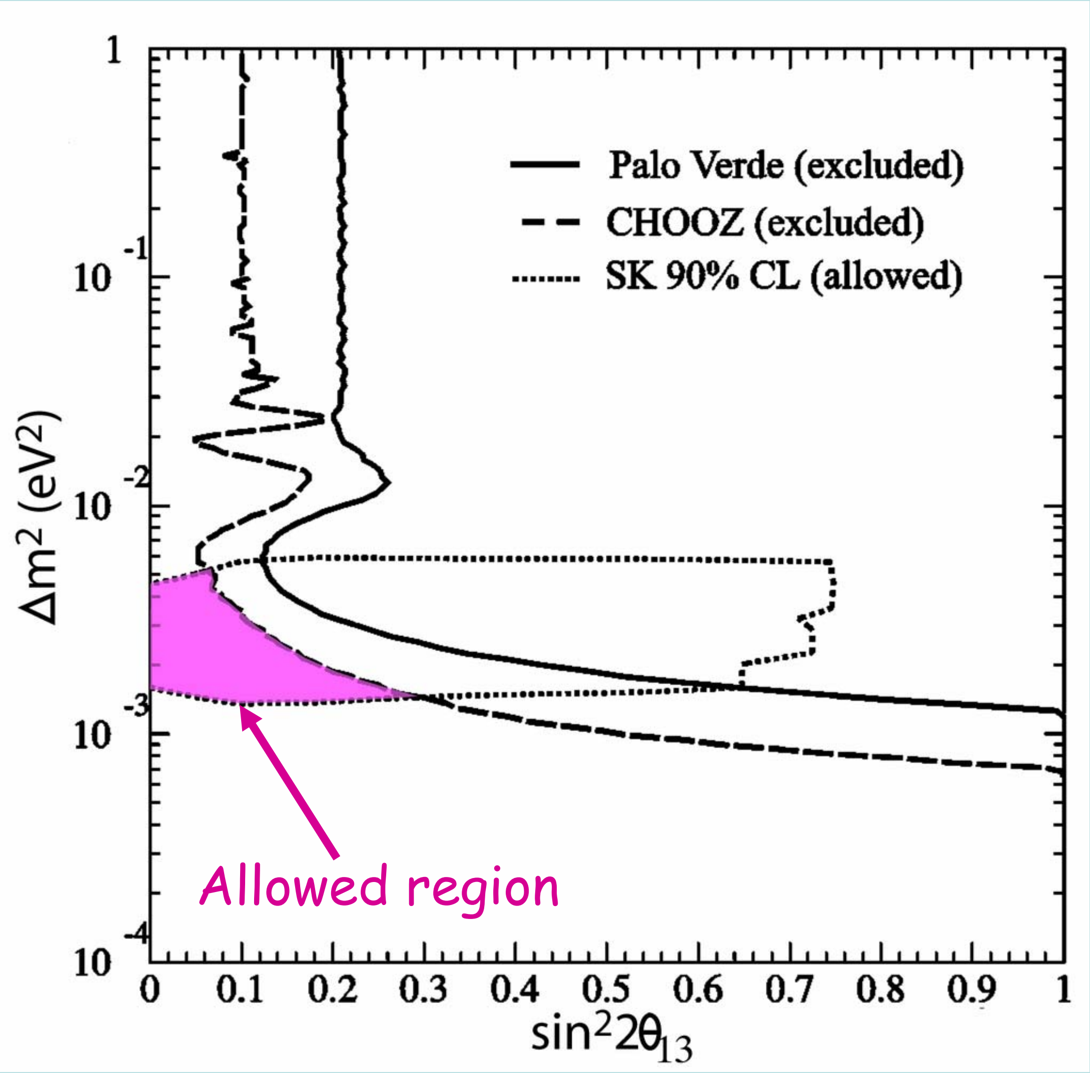




Bugey results, ratio to predicted flux (15-40m)

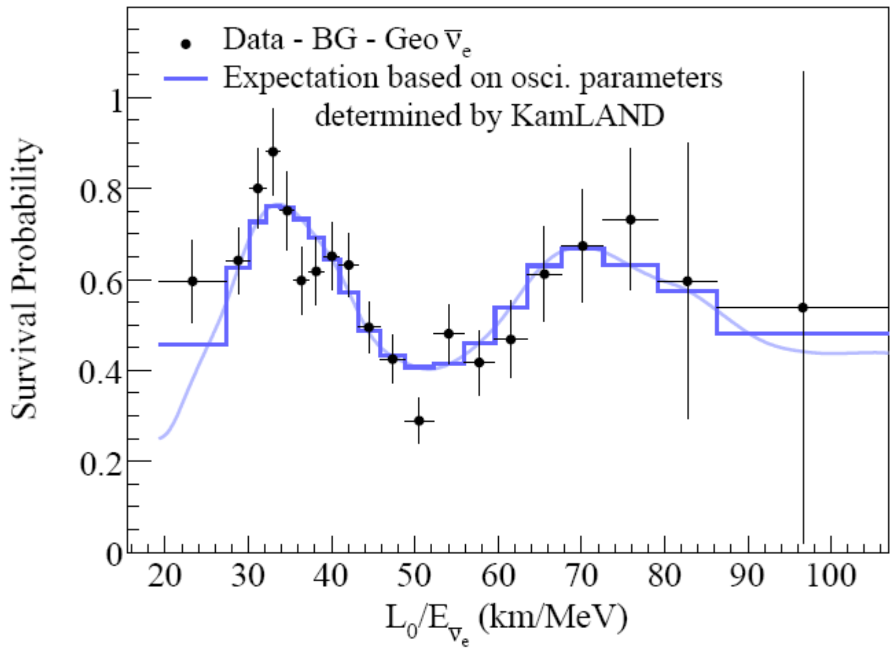
Flux and spectrum well-understood @ ~1-2%

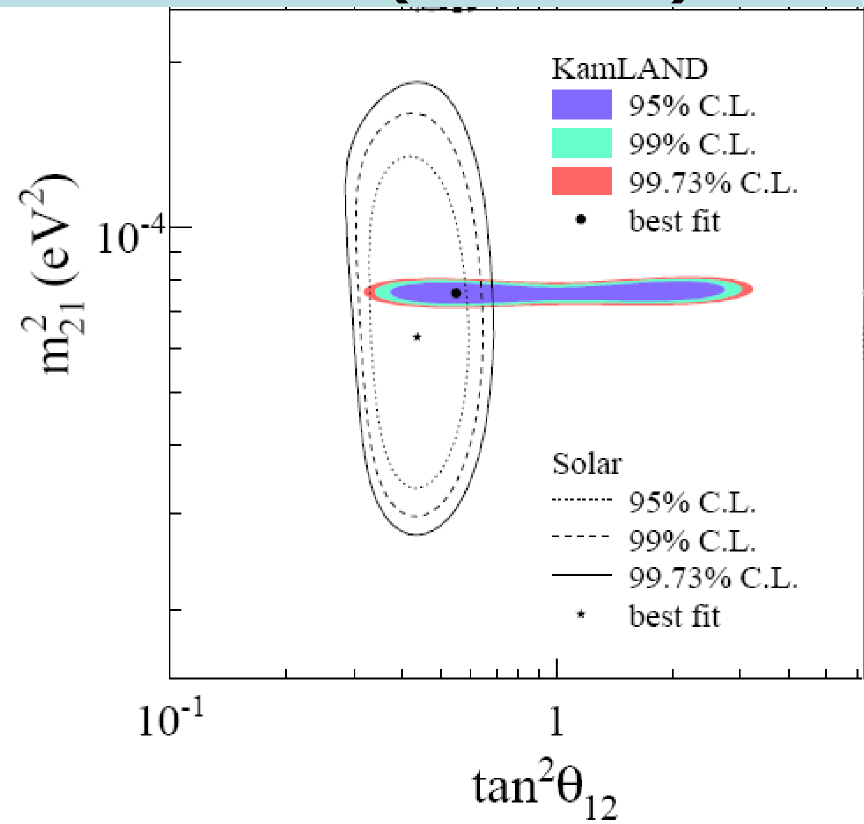
CHOOZ/Palo Verde limits for θ_{13}



At $\Delta m^2_{31} = 2.5 \times 10^{-3}$ eV^2, $\sin^2 2\theta_{13} < 0.15$

KamLAND Result (2008)





arXiv:0801.4589v2 [hep-ex]

Best combined fit values:

$\Delta m^2 = 7.59^{+0.21}_{-0.21} \times 10^{-5}$ eV^2

$\tan^2\theta = 0.47^{+0.06}_{-0.05}$

3 New Reactor θ_{13} Experiments

Double CHOOZ (France)

RENO (South Korea)

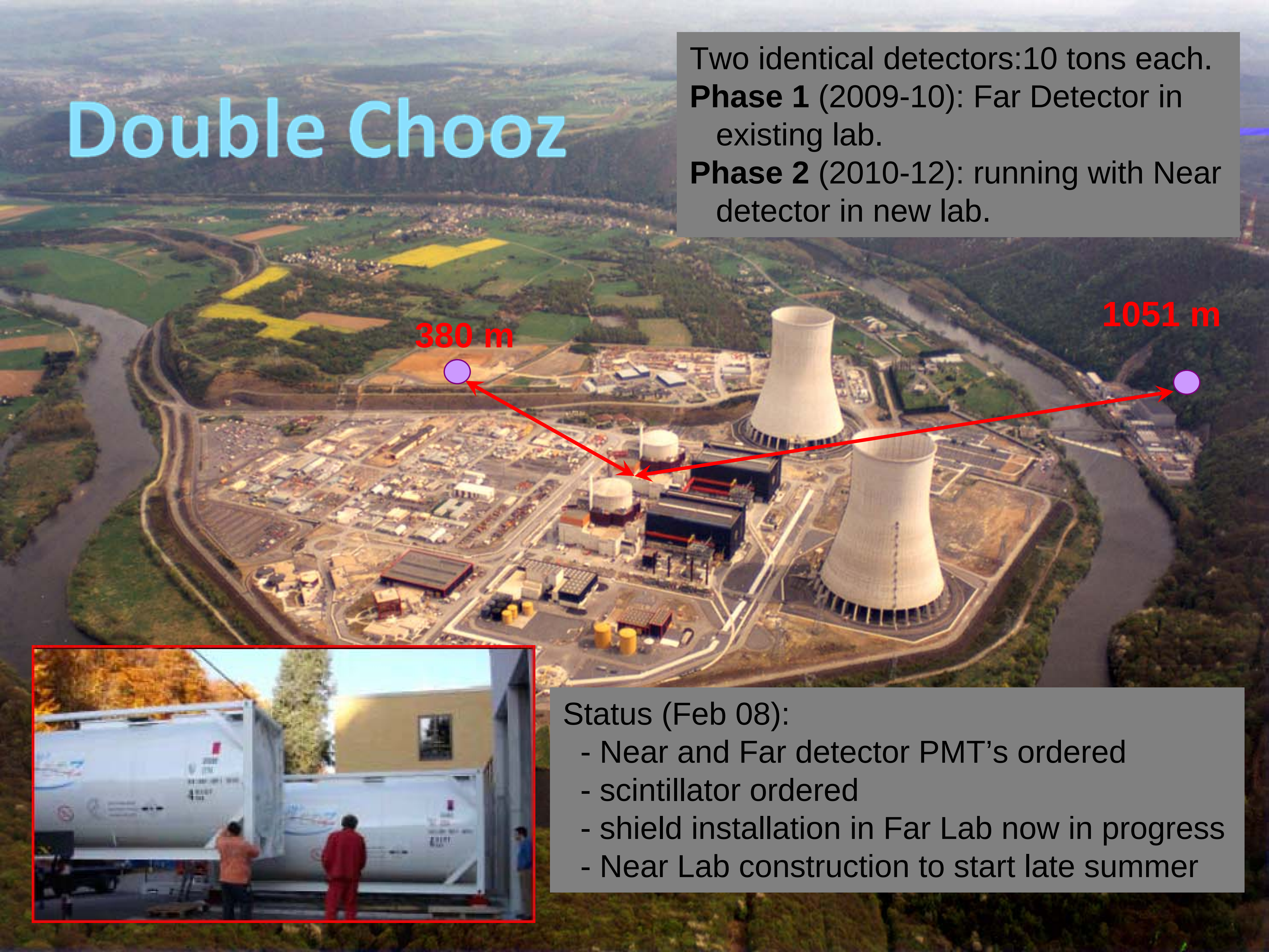
Daya Bay (China)

Double Chooz

Two identical detectors:10 tons each.

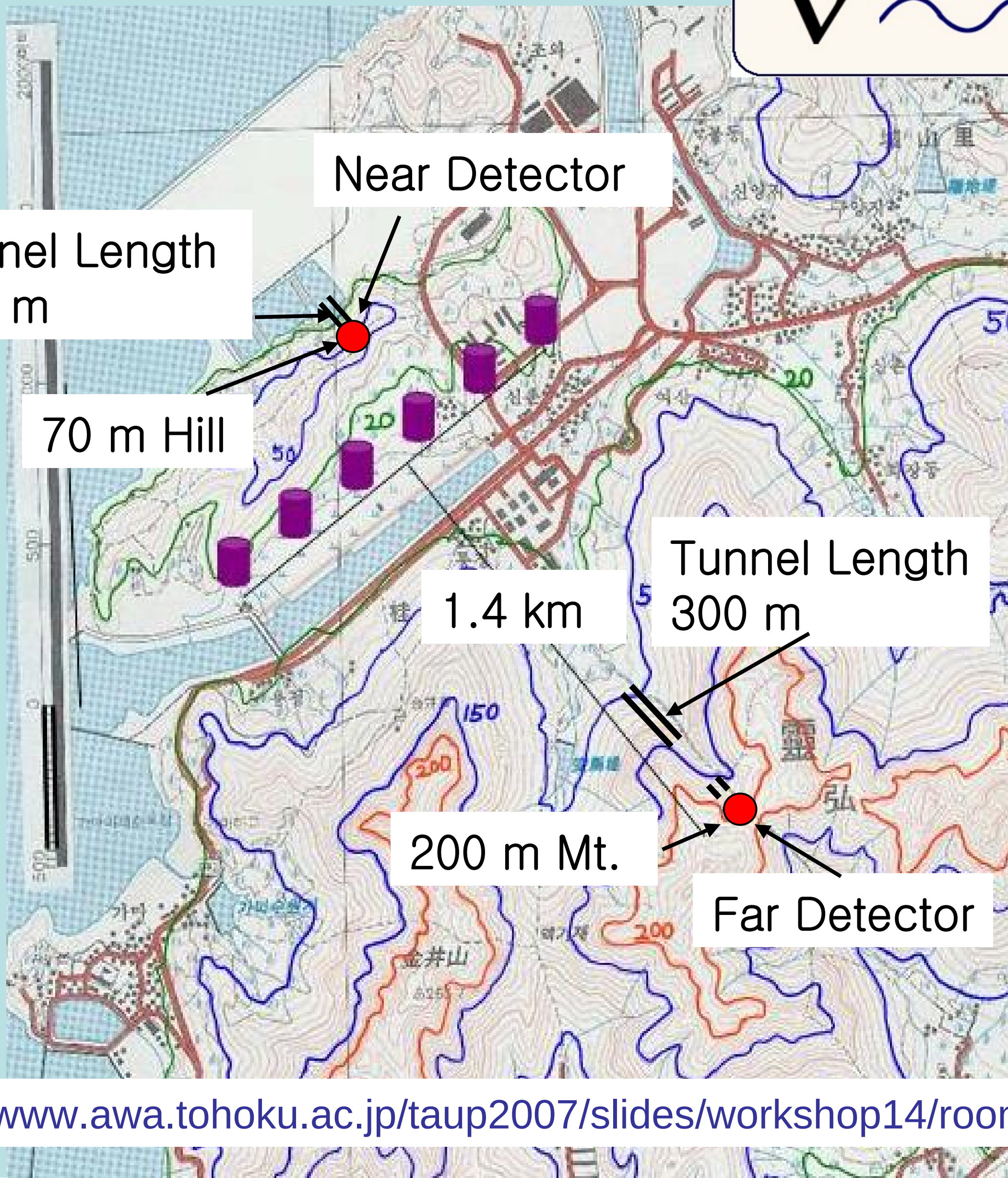
Phase 1 (2009-10): Far Detector in existing lab.

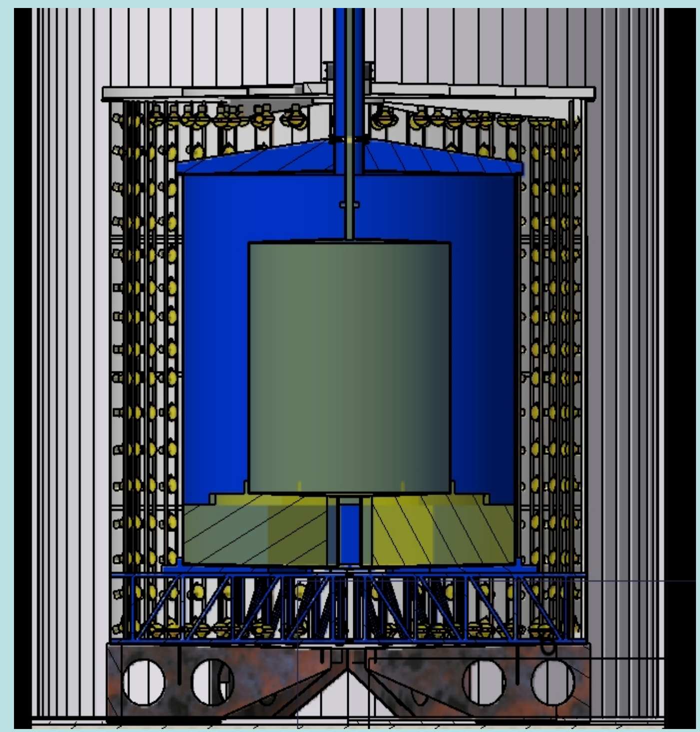
Phase 2 (2010-12): running with Near detector in new lab.



Status (Feb 08):

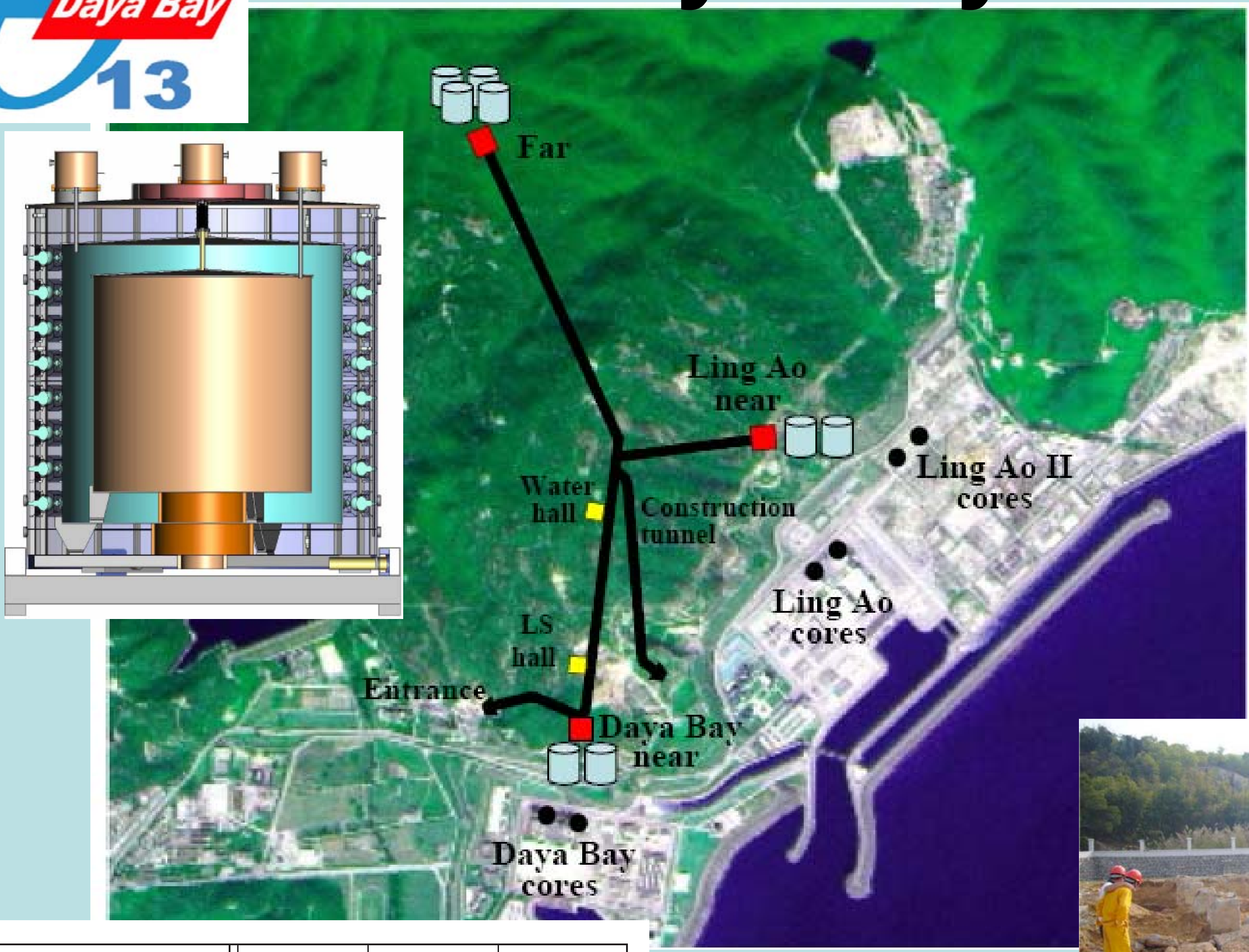
- Near and Far detector PMT’s ordered
- scintillator ordered
- shield installation in Far Lab now in progress
- Near Lab construction to start late summer





http://www.awa.tohoku.ac.jp/taup2007/slides/workshop14/roomA/05-RENO-TAUP07.ppt

Daya Bay



- Multiple detectors per site cross-check detector efficiency
- Two near sites sample flux from reactor groups
- Civil construction underway

	DYB	LA	Far
DYB cores	363	1347	1985
LA cores	857	481	1618
LA II cores	1307	526	1613

Total Tunnel length ~ 3000 m

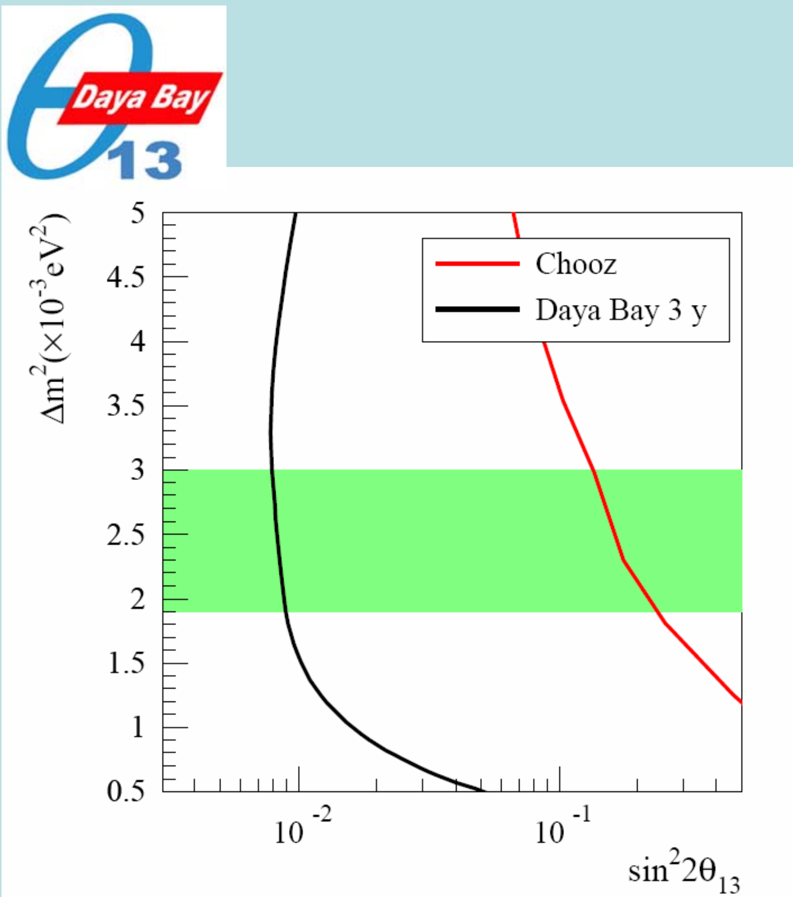
Comparison Table

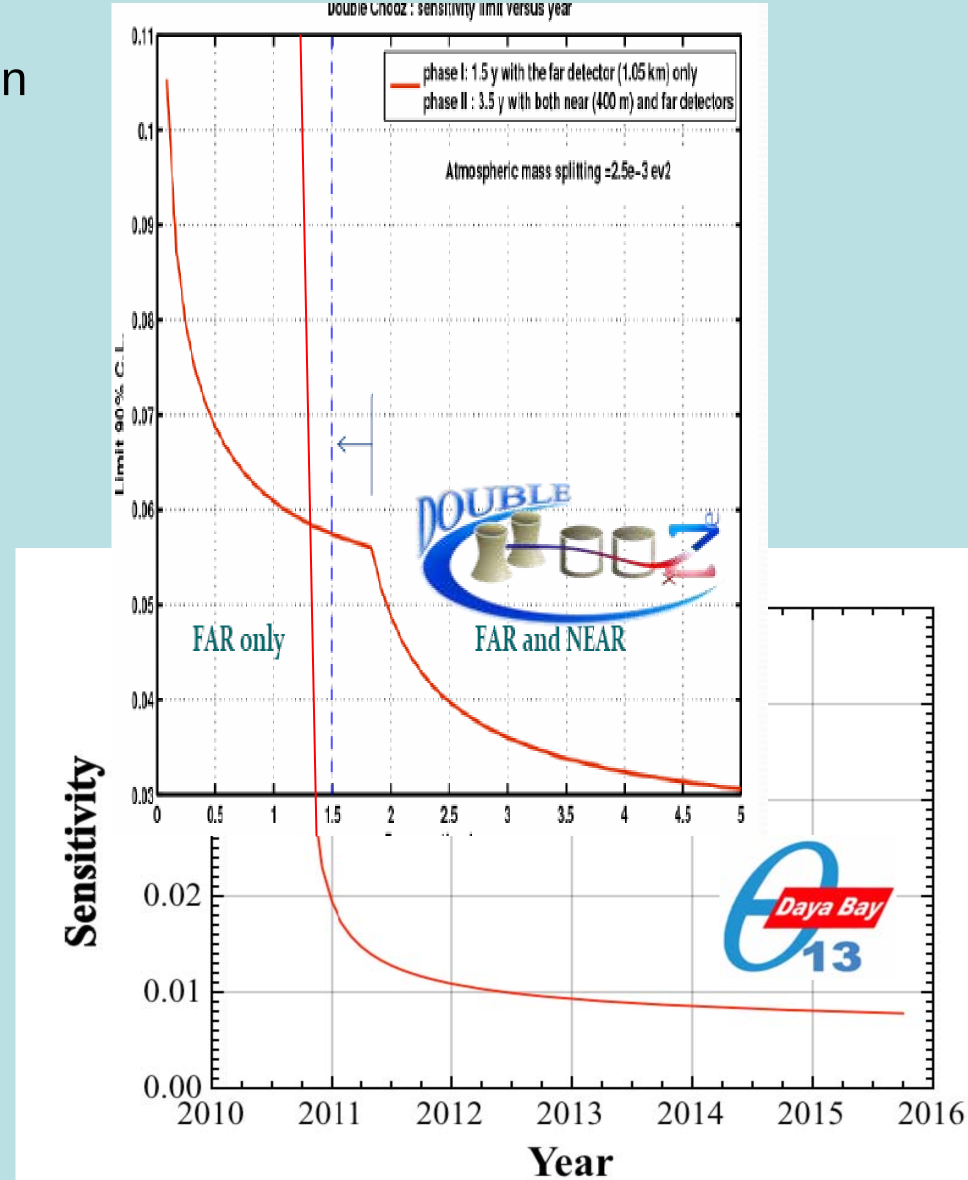
Experiment	Thermal Power (GW)	Distances Near/Far (m)	Depth Near/Far (mwe)	Target Mass (tons)	Start Date	Sensitivity @2.5x10^{-3} eV^2 90% CL, 3 years
Double-CHOOZ (France)	8.6	380/1050	120/300	8.3/8.3	6/2009, 12/2010	0.03
RENO (So. Korea)	17.3	290/1380	120/450	15/15	1/2010	0.02
Daya Bay (China)	17.4	360(500) / 1985(1613)	260/910	40($\times$2) / 80	12/2010	0.008

Sensitivity to $\sin^2 2\theta_{13}$

Figures from:

- Daya Bay TDR (Jan. 2008)
- Double-CHOOZ HEPAP presentation (Feb. 14, 2008)





Summary

- Reactor neutrino experiments have entered "precision era"
- RENO, Double-CHOOZ, Daya Bay will study θ_{13} during 2010-14, reaching $\sin^2 2\theta_{13} < 0.01$
- R&D work in progress for
  - non-proliferation monitoring (several)
  - future large moveable detectors (Hawaii)

Backup Slides

Daya Bay Funding Profile

Table 5-1. DOE Funding ($K)			
Fiscal Year	**TEC**	**OPC**	**Total**
2007	500	500	1,000
2008	3,000	2,000	5,000
2009	9,000	0	9,000
2010	11,000	0	11,000
2011	7,518	482	8,000
Total	**31,018**	**2,982**	**34,000**

Daya Bay CD-2 Report

6.3 Recommendations

1. Ready for both CD-2 and, with the minor prerequisites stated elsewhere, CD-3a for all the items requested.

2. Sign the MOUs. Make the minor consistency corrections, such as incorporating the updated CD-4 goals into the PEP, to the project documents and present for signature.

3. Continue the valuable and comprehensive Program Advisory Panel (PAP) process as the project transitions into construction and installation.

4. Continue to place high importance on ES&H and implement the plans developed over the past few months in a timely way and monitor their effectiveness.