Reactor Neutrino Measurement of q_{13}

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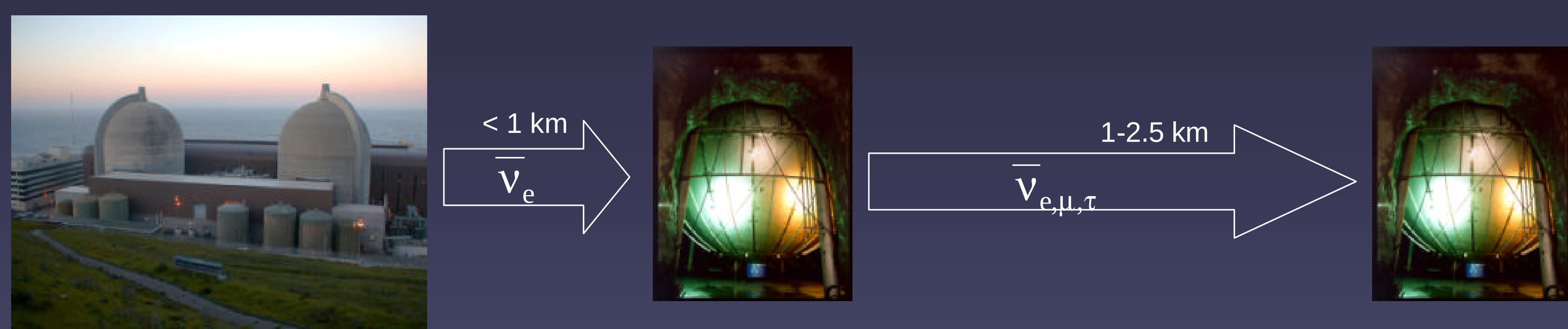
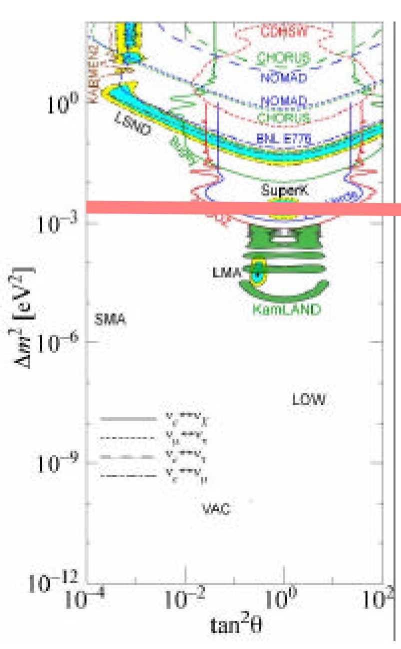
http://theta13.lbl.gov/

Measuring q_{13} at a Reactor

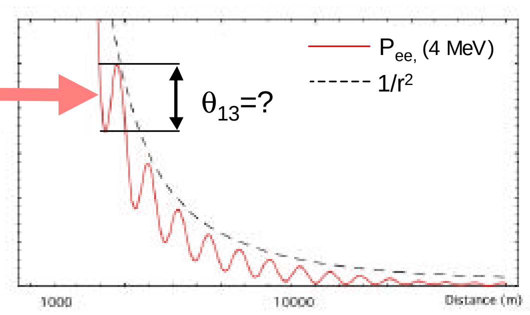


A novel reactor antineutrino experiment

- 2 or 3 antineutrino detectors
- variable baseline



Reactor antineutrino flux as a function of distance from the reactor.



Deviation of the reactor antineutrino flux from the $1/r^2$ law due to neutrino oscillations.

$$P_{ee} \approx 1 - \sin^2 2q_{13} \sin^2 \frac{\Delta m_{31}^2 L}{4E_n} + \left(\frac{\Delta m_{21}^2 L}{4E_n}\right) \cos^4 q_{13} \sin^2 2q_{12}$$

With multiple detectors and a variable baseline a next-generation reactor neutrino experiment has the opportunity to discover subdominant neutrino oscillations associated with the atmospheric mass splitting and make a measurement of θ_{13}.

A reactor neutrino oscillation experiment

- is a disappearance experiment
- searches for deviations from $1/r^2$ law in relative $\bar{\nu}_e$ flux and spectral shape between detectors
- uses a baseline of *O*(1 km)
- encounters no matter effects

Understanding the U_{MNS} Neutrino Mixing Matrix

Results of the SNO solar neutrino experiment, the KamLAND reactor antineutrino experiment, and the evidence from the Super-Kamiokande atmospheric neutrino experiment have established the massive nature of neutrinos and point to a novel phenomenon called *neutrino oscillations*.
In the framework of neutrino oscillations the mass and flavor eigenstates of 3 active species are related through the U_{MNS} matrix.

Past, Present and Future Experiments

$$U = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{m1} & U_{m2} & U_{m3} \\ U_{t1} & U_{t2} & U_{t3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos q_{23} & \sin q_{23} \\ 0 & -\sin q_{23} & \cos q_{23} \end{pmatrix} \times \begin{pmatrix} \cos q_{13} & 0 & e^{-id_{CP}} \sin q_{13} \\ 0 & 1 & 0 \\ -e^{id_{CP}} \sin q_{13} & 0 & \cos q_{13} \end{pmatrix} \times \begin{pmatrix} \cos q_{12} & \sin q_{12} & 0 \\ -\sin q_{12} & \cos q_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \times \begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{ia/2} & 0 \\ 0 & 0 & e^{ia/2+ib} \end{pmatrix}$$

Dirac phase — Majorana phases

atmospheric ν present, accelerator ν future — reactor and accelerator ν future — solar ν present, solar ν future — 0νββ experiments future

A variety of experiments are needed to determine all elements of the neutrino mixing matrix. The angle θ_{13} associated with the subdominant oscillation is still undetermined!

solar	θ_{12} = 33°	*large*
atmospheric	θ_{23} = ~ 45°	*maximal*
Chooz, Palo Verde, SK	$\tan^2\theta_{13}$ < 0.03 at 90% CL	*small … at best*

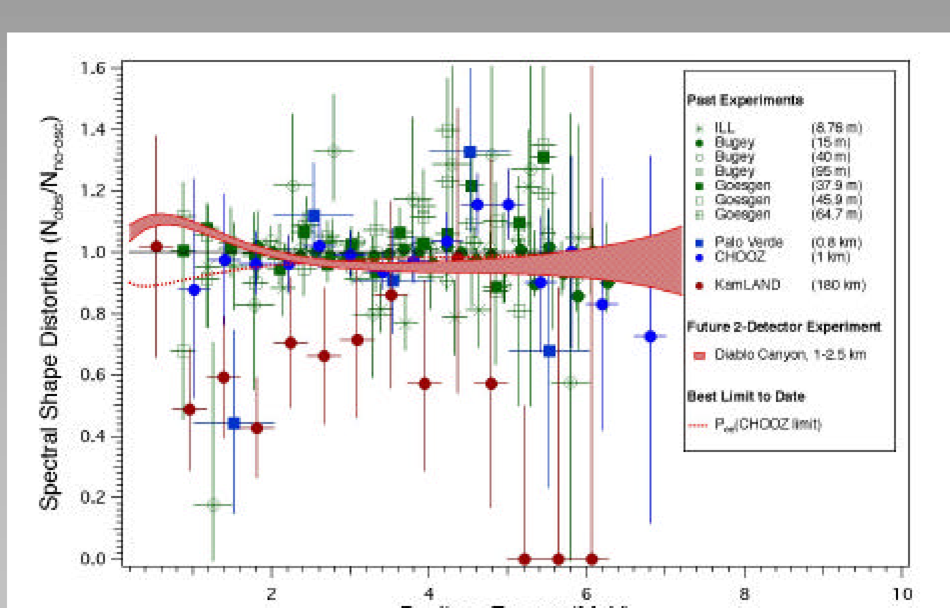
Future reactor neutrino experiments with multiple detectors have the opportunity to measure the last undetermined mixing angle θ_{13}. Knowing θ_{13} will be critical for establishing the feasibility of CP violation searches in the lepton sector.

Understanding the Role of q_{13} in Neutrino Oscillation Physics

- Why are the mixing angles *large, maximal,* and *small*?
- Is there CP, T, or CPT violation in the lepton sector?
- Is there a connection between the lepton and the baryon sector?
- Understanding the role of neutrinos in the early Universe:

Can leptogenesis explain the baryon asymmetry?

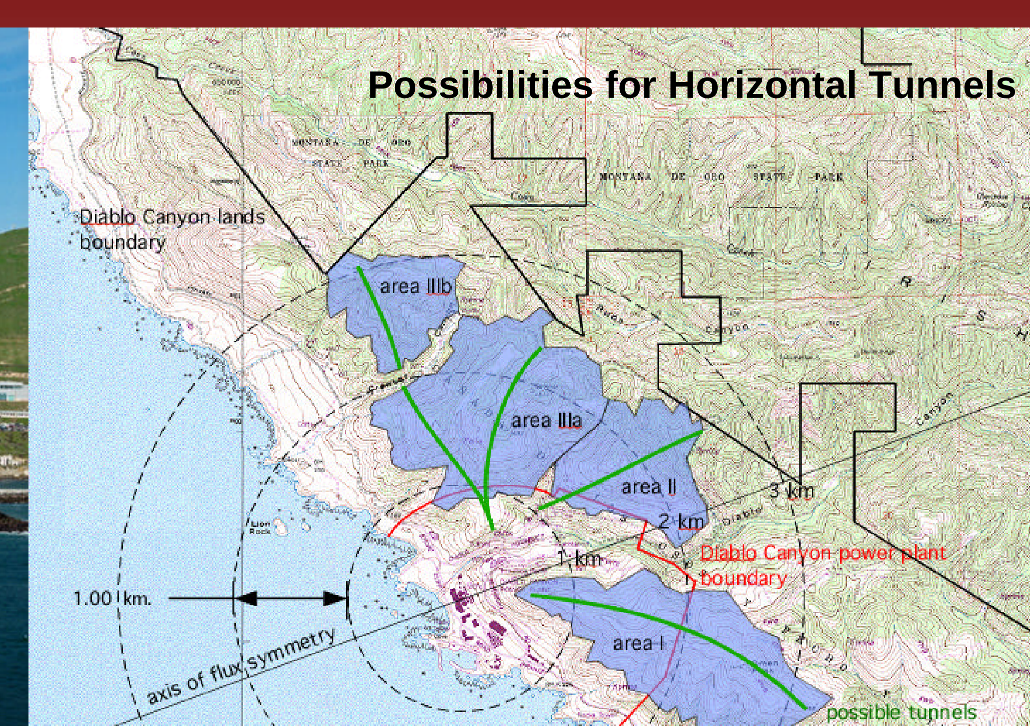
Towards a Precision Reactor Neutrino Oscillation Experiment

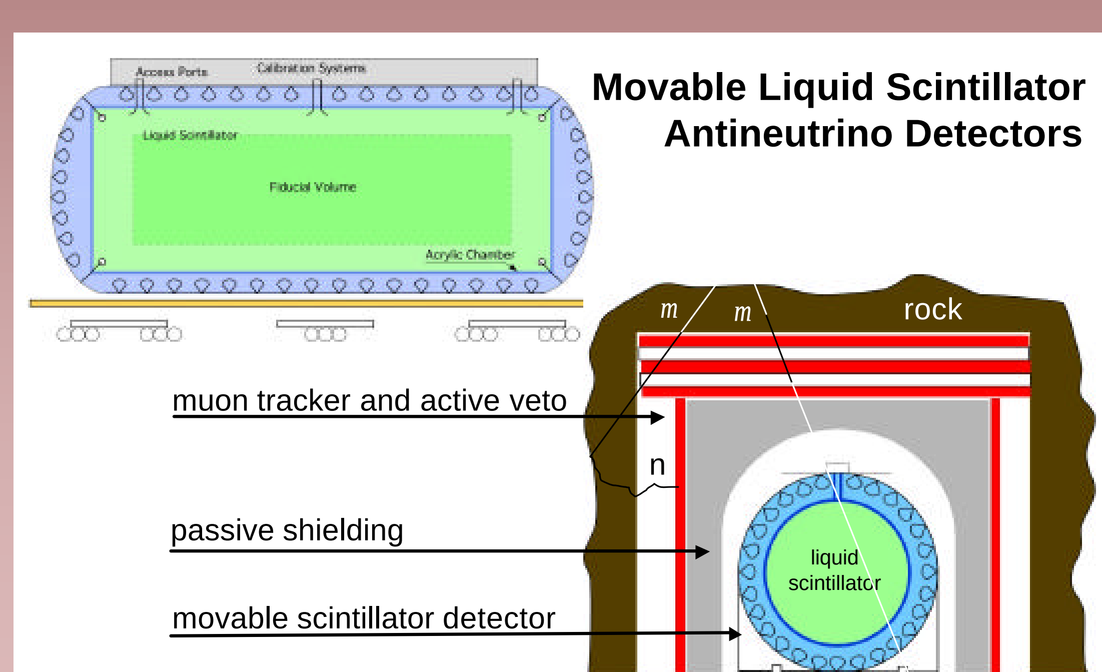


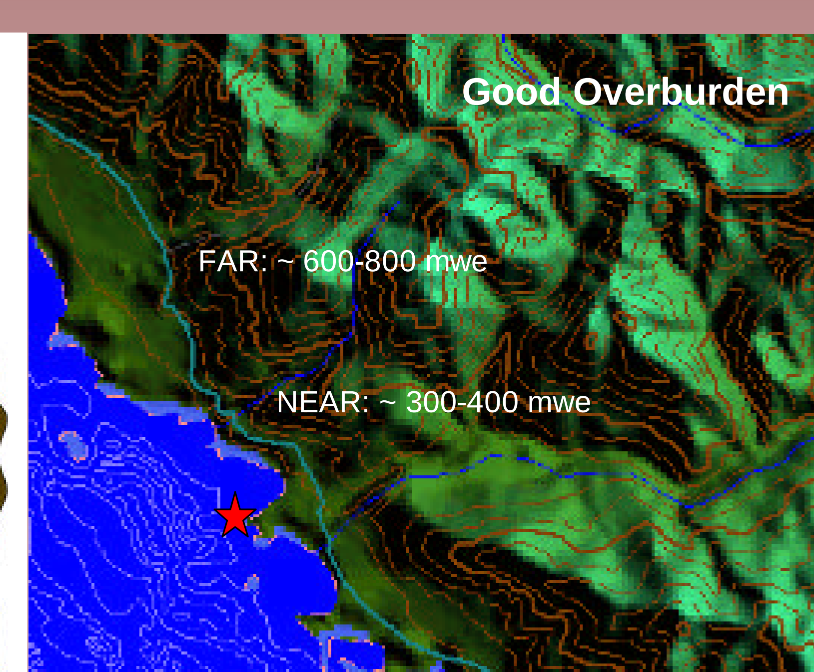
Results from past reactor neutrino experiments (statistical error) compared to the expected statistical sensitivity of a next-generation, 2-detector reactor oscillation experiment. The expected sensitivity is $\sin^2 2\theta_{13}$ ~ 0.01-0.02.

Diablo Canyon, California - An Ideal Site?

- ***Powerful:*** Two reactors (3.1+ 3.1 GW E_{th})
- ***Overburden:*** Horizontal tunnel with ~ 800 mwe shielding.
- ***Infrastructure:*** Construction roads. Controlled access.







Modular and movable detectors with a volume of ~100 tons combined with an active muon veto allow a precision measurement of θ_{13}.
A variable baseline is critical for controlling systematics and demonstrating the subdominant oscillation effect associated with θ_{13}.

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