Reactor Neutrino Measurement of θ_{13}

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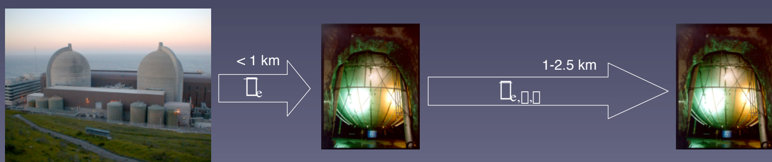
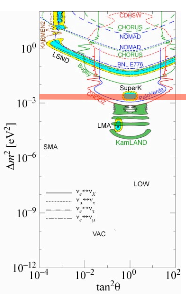
http://theta13.lbl.gov/

Measuring θ_{13} at a Reactor

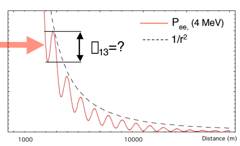


A novel reactor antineutrino experiment

- 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.

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

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 $\mathcal{O}$(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

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

$$= \underbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix}}_{\substack{\text{atmospheric } \nu \text{ present} \\ \text{accelerator } \nu \text{ future}}} \times \underbrace{\overbrace{\begin{pmatrix} \cos\theta_{13} & 0 & e^{-i\delta_{CP}}\sin\theta_{13} \\ 0 & 1 & 0 \\ -e^{i\delta_{CP}}\sin\theta_{13} & 0 & \cos\theta_{13} \end{pmatrix}}^{\text{Dirac phase}}}_{\substack{\text{reactor and accelerator } \nu \\ \text{future}}} \times \underbrace{\begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}}_{\substack{\text{solar } \nu \text{ present} \\ \text{solar } \nu \text{ future}}} \times \underbrace{\overbrace{\begin{pmatrix} 1 & 0 & 0 \\ 0 & e^{i\alpha/2} & 0 \\ 0 & 0 & e^{i\alpha/2+i\beta} \end{pmatrix}}^{\text{Majorana phases}}}_{\substack{0\nu\beta\beta \text{ experiments} \\ \text{future}}}$$

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

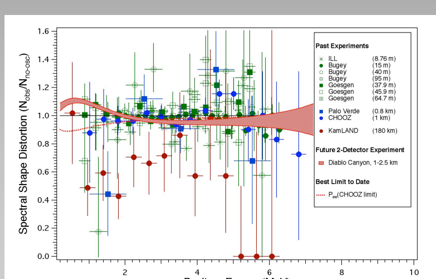
Future reactor neutrino experiments with multiple detectors have the opportunity to measure the last undetermined mixing angle θ_{13} . Knowing θ_{13} will be critical for establishing the feasibility of CP violation searches in the lepton sector.

Understanding the Role of θ_{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:

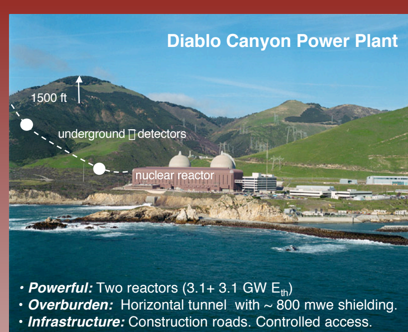
Can leptogenesis explain the baryon asymmetry?

Towards a Precision Reactor Neutrino Oscillation Experiment

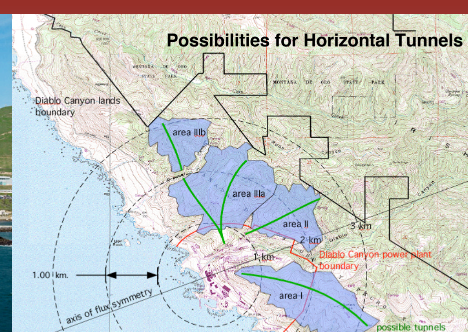


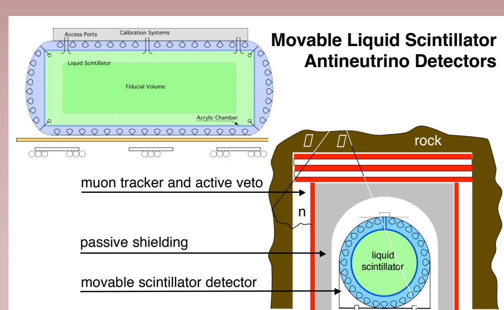
Results from past reactor neutrino experiments (statistical error) compared to the expected statistical sensitivity of a next-generation, 2-detector reactor oscillation experiment. The expected sensitivity is $\sin^2 2\theta_{13} \sim 0.01$-$0.02$.

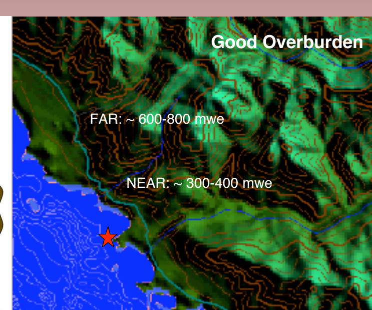
Diablo Canyon, California - An Ideal Site?



- ***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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