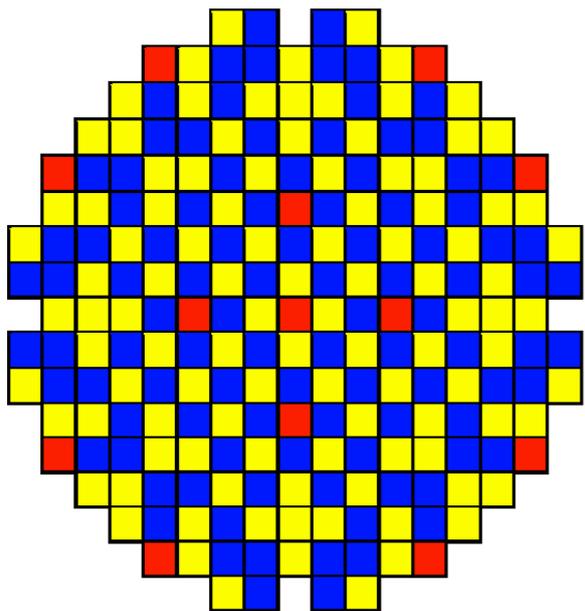


Simulation of SONGS Reactor Antineutrino Flux Using DRAGON

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11 March 2010
Moriond EW



Motivation: Improving on CHOOZ

CHOOZ Reactor-based Uncertainties

Systematic	% Error
ν flux	1.9
Energy per fission	0.6
Reactor Power	0.6
ν per fission	0.2
ν cross section	0.1

Unless reactor-based uncertainties can be removed, reactor simulations are **necessary** to push down the lower limit of θ_{13} !

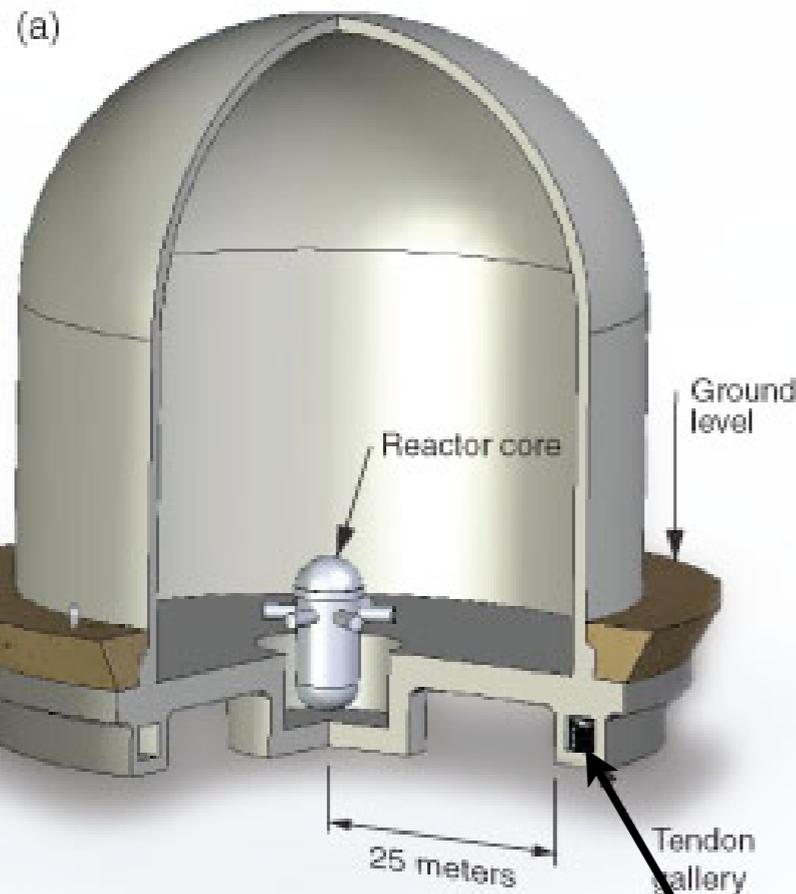
$$\sin^2 2\theta_{13} < 0.19$$

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} \approx \begin{pmatrix} 0.8 & 0.6 & e^{i\delta} \sin \theta_{13} \\ -0.4 & 0.6 & 0.7 \\ 0.4 & -0.6 & 0.7 \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

Flavor eigenstates
Mass eigenstates

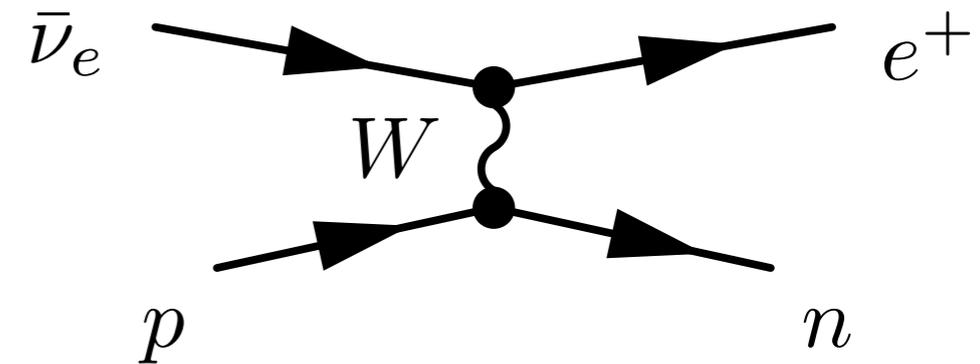
SONGS: Detector and Reactor

San Onofre Nuclear Generating Station



SONGS reactor:
3.438 GWth
output

SONGS detector:
0.64 ton liquid scintillator
doped with Gd

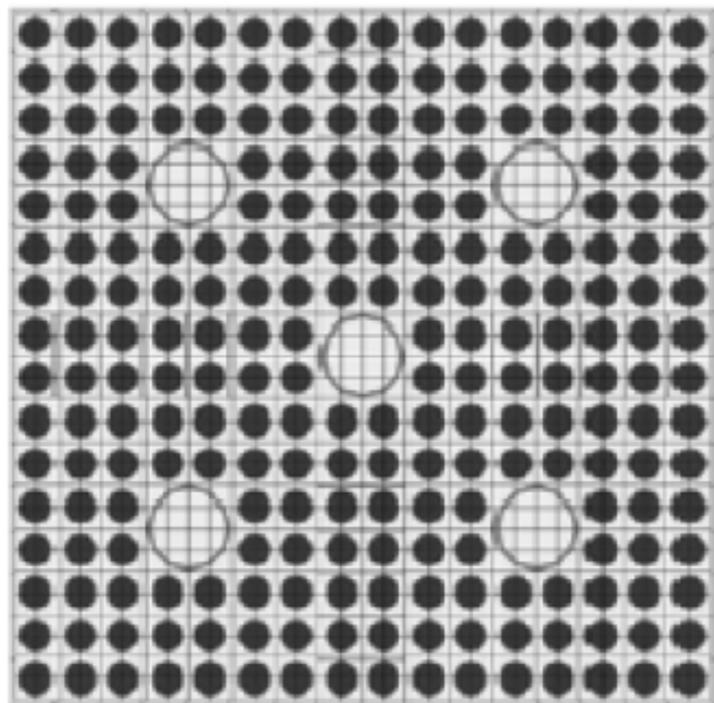


Detection method:
Inverse β decay

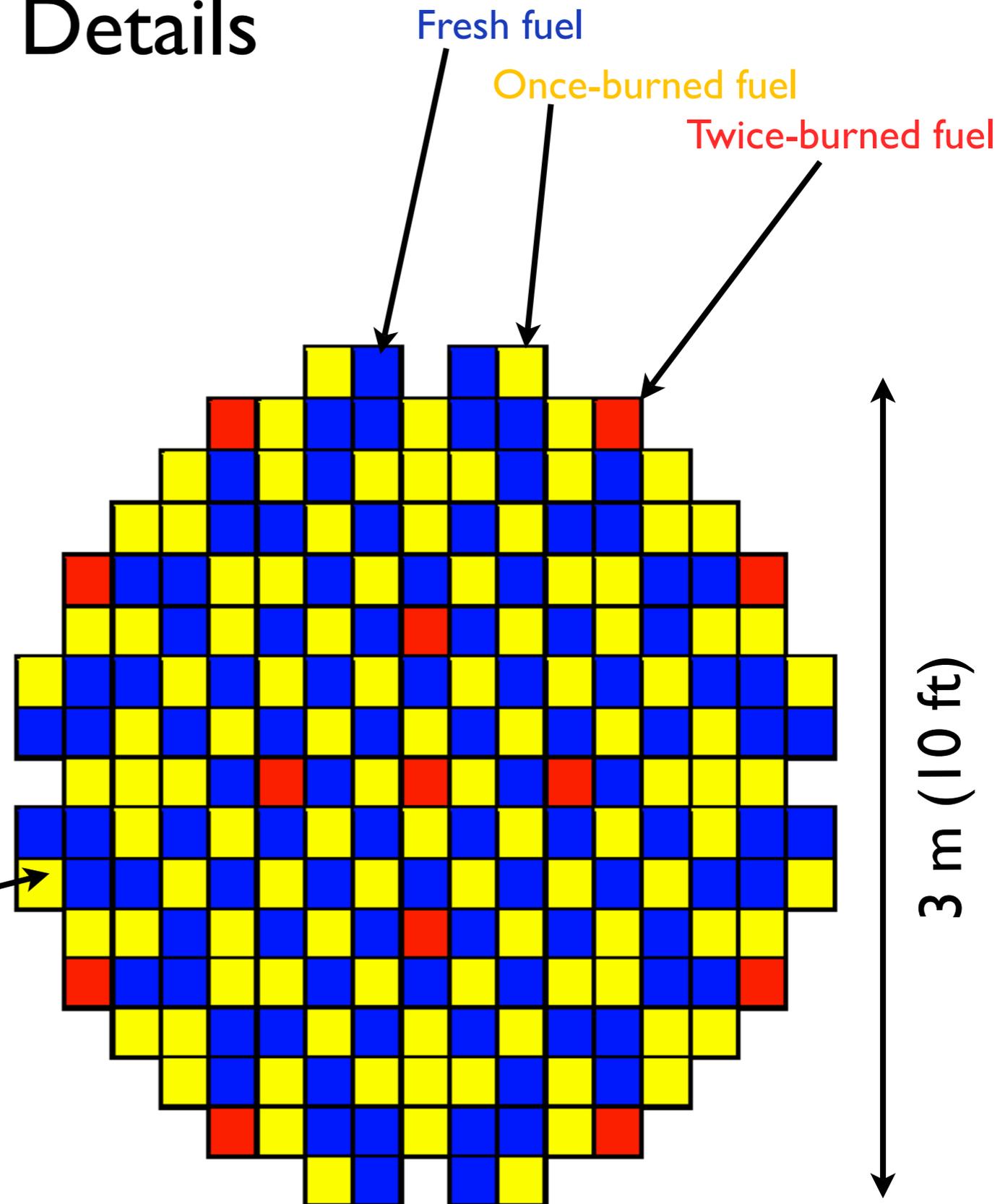
SONGS Reactor Assembly Details

- 16 x 16 PWR
- 236 fuel rods per assembly
- 217 assemblies in the core
- 3.81 m in height

Our code, DRAGON,
simulates
assemblies



Westinghouse CE fuel assembly

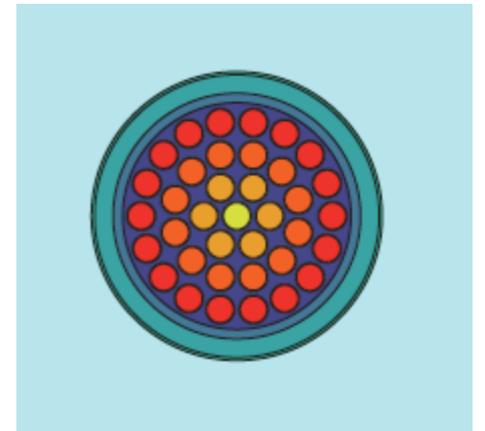


SONGS Core Map

The DRAGON Code



- Deterministic code that solves neutron transport equation in an assembly of heterogeneous cells
- Output can be interfaced to do full core calculation
- Using customized version to extract fission rates, which are crucial to predict the antineutrino rate

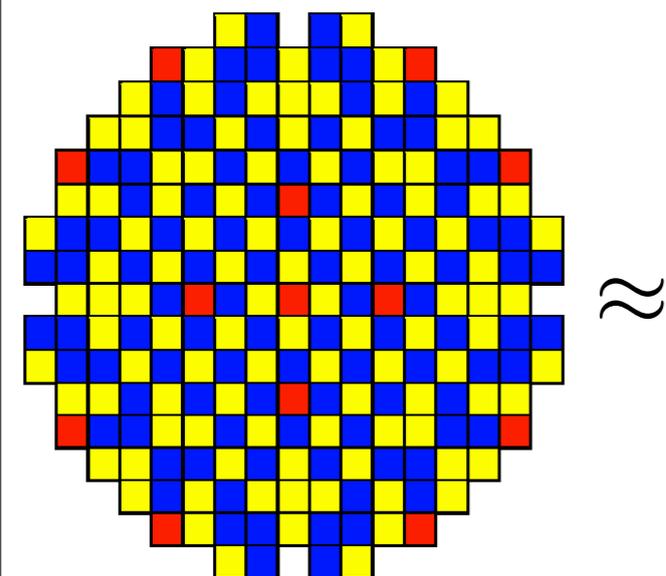


Fuel Cell

Calculating the Antineutrino Rate

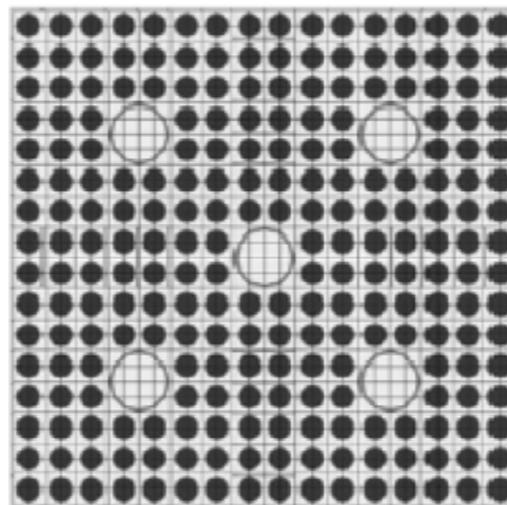
$$\frac{dN_\nu}{dt} = \zeta \sum_i^{\text{assemblies}} \int_{1.8}^{\infty} dE_i \left(\frac{P_i(t)}{\sum_{k=1}^4 f_i^k(t) E^k} \right) \cdot \left(\sum_{k=1}^4 f_i^k(t) S^k(E_i) \right) \sigma_{IBD}(E_i)$$

In this approximation, detector response variables are encoded in this variable ζ
 Thermal power in i th assembly $P_i(t)$
 Sum over fissile nuclei $\sum_{k=1}^4 f_i^k(t) E^k$
 fission rate from DRAGON $f_i^k(t)$
 Energy per fission E^k
 Schreckenbach spectra $S^k(E_i)$



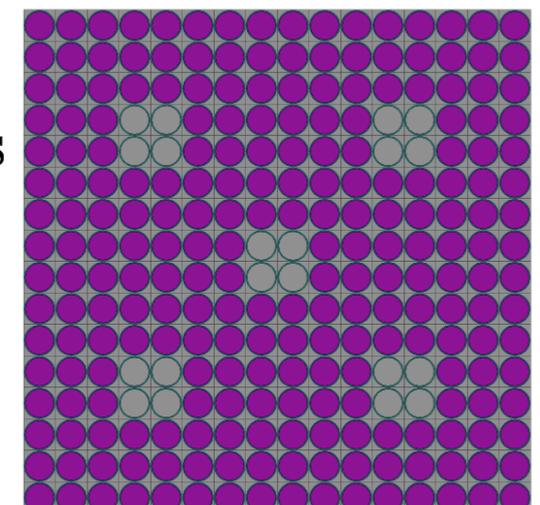
\approx

assemblies \sum_i



\approx

assemblies \sum_i



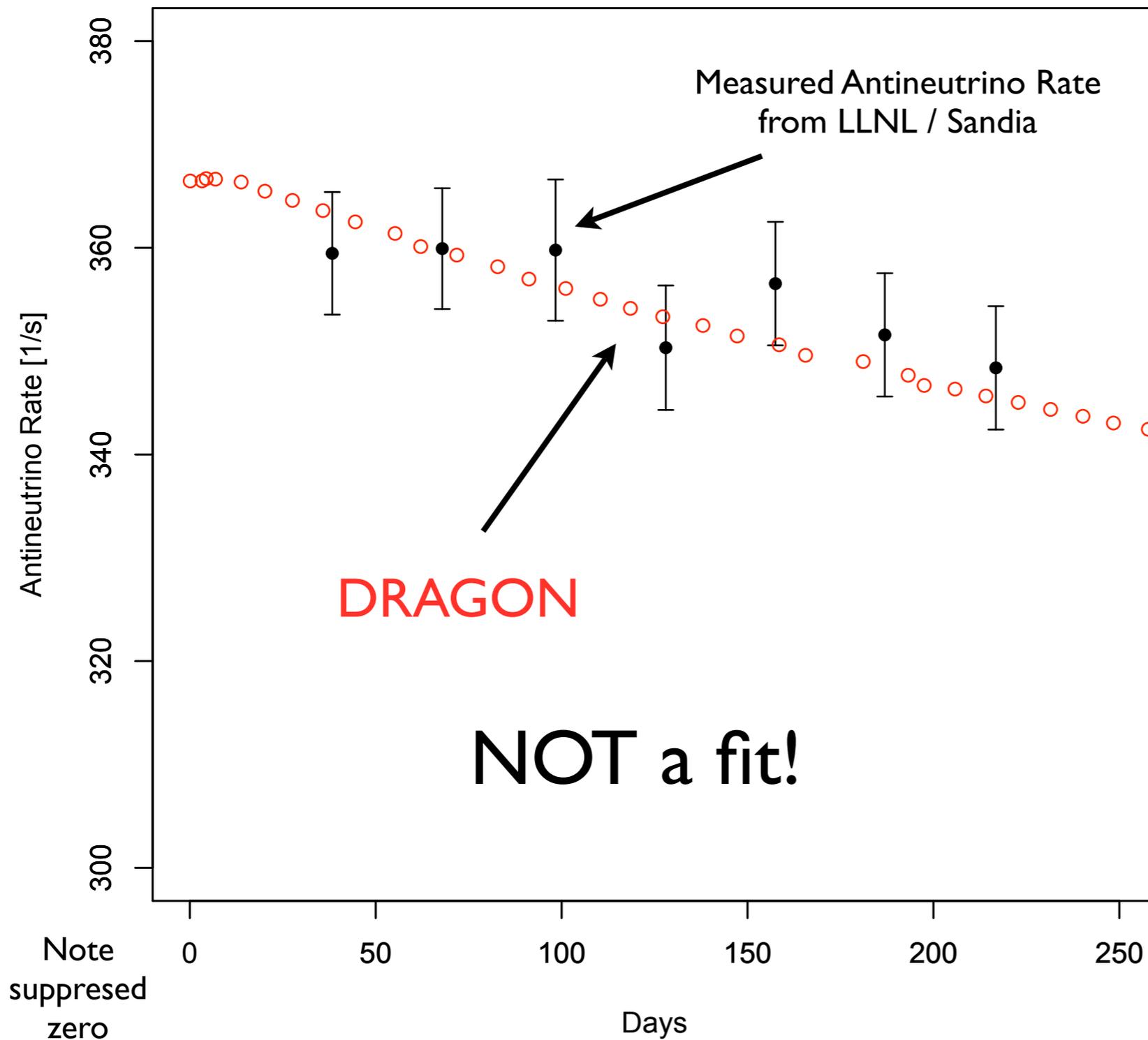
actual SONGS core

Westinghouse 16 x 16 CE assembly

DRAGON assembly

DRAGON / Data Comparison

SONGS Cycle 13



-Slope agrees with measured data
(with arbitrary normalization)

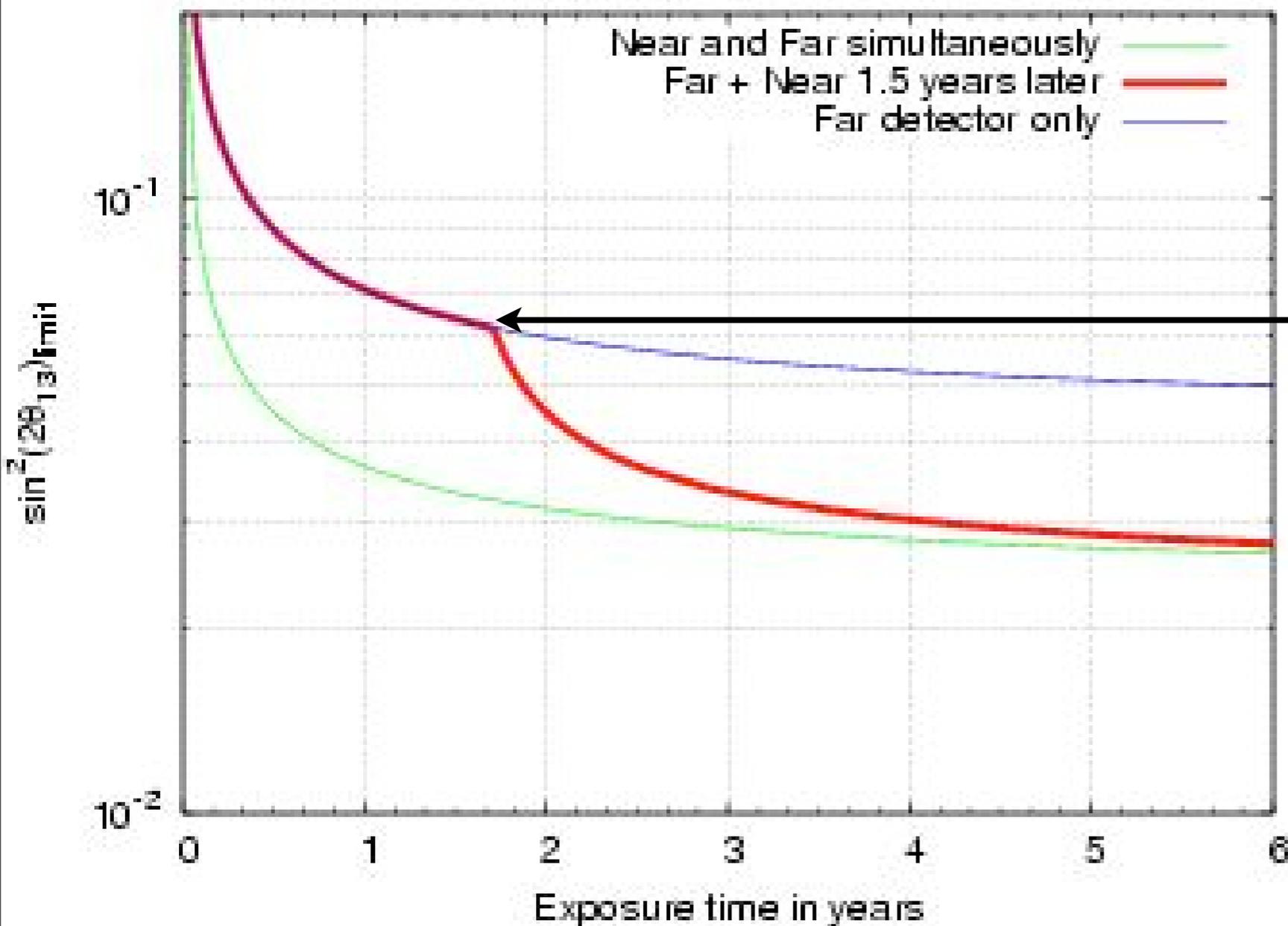
-Next steps:
getting correct
absolute normalization

Future Work

- Use DRAGON's companion code DONJON to simulate a full reactor core
- Incorporate data from 2 different cycles into simulation to observe end-of-cycle / beginning-of-cycle transition for nonproliferation efforts
- Several other benchmark studies with DRAGON are underway to ascertain systematic errors

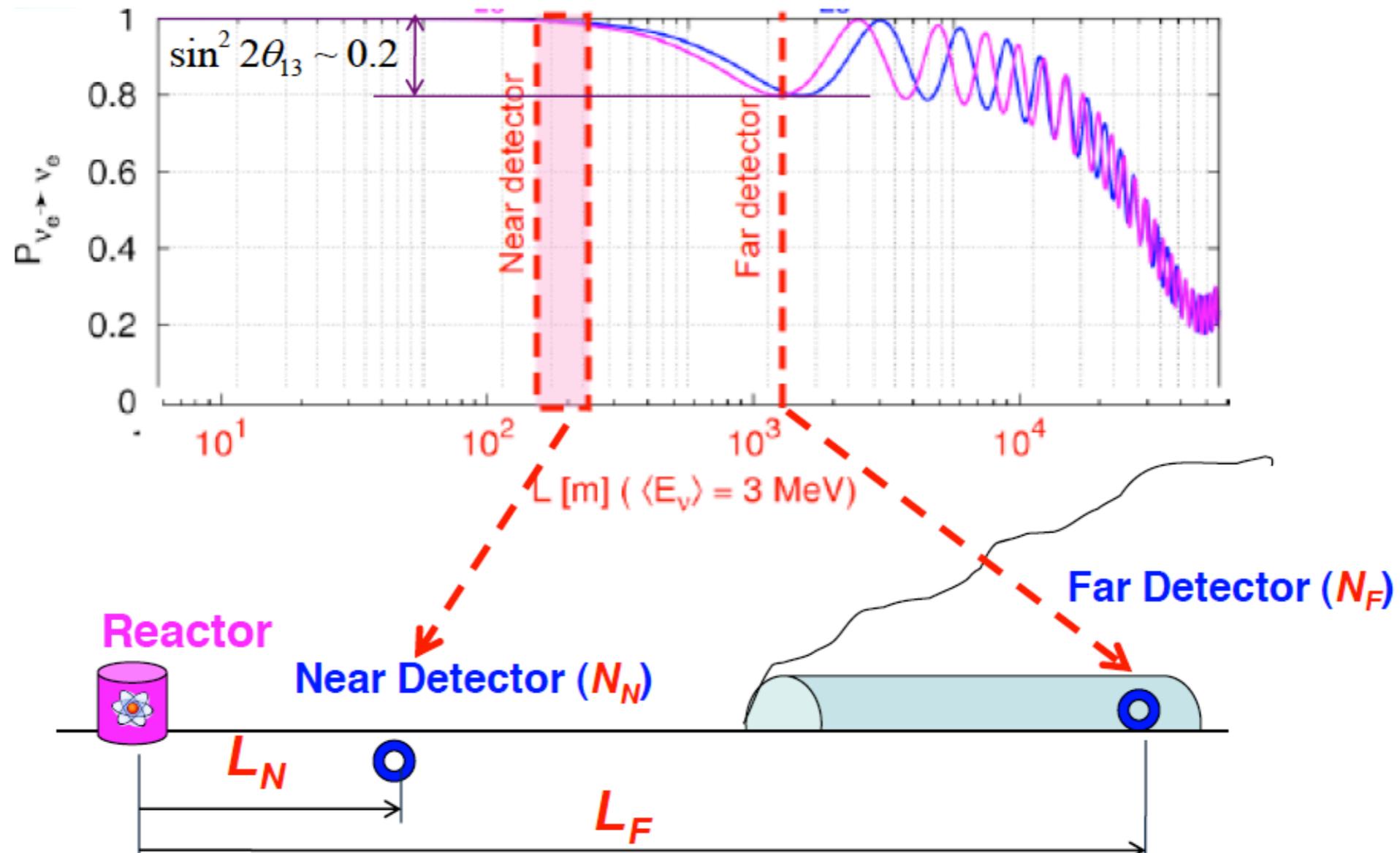
Extra Slides

Importance of Reactor Simulations For Double Chooz



Until Near Detector is activated, reactor simulations are the only way to extract θ_{13} !

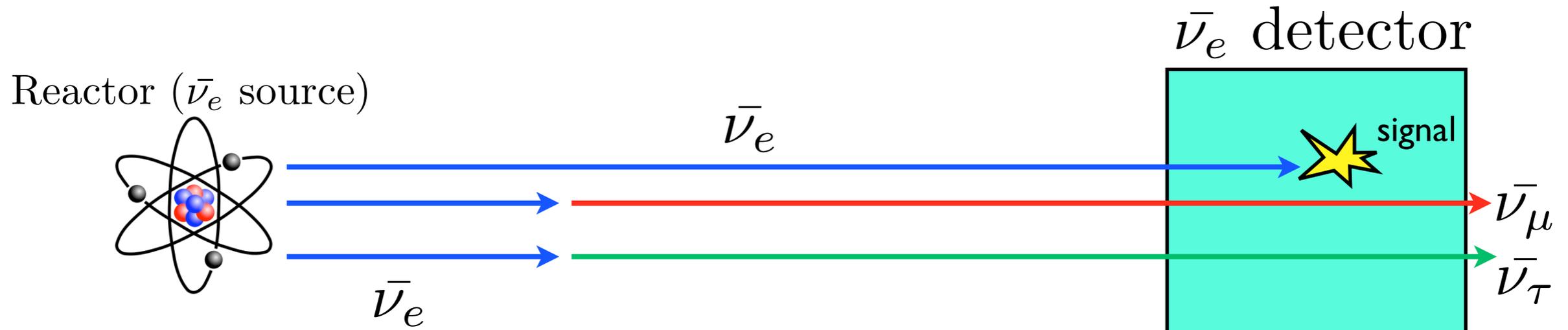
Double Chooz: Improving on Previous Experiments



-The identical detectors will cancel systematic errors in flux and detector response

-Far detector already in place

Reactor Antineutrino Experiment



In a *disappearance experiment*, we look for a deficit of electron antineutrinos.

Survival probability

$$P_{ee}(E_{\bar{\nu}_e}, L, \Delta m_{13}^2, \theta_{13}) = 1 - \sin^2(2\theta_{13}) \sin^2 \left(1.27 \frac{\Delta m_{13}^2 [10^{-3} \text{eV}^2] L [\text{km}]}{E_{\bar{\nu}_e} [\text{MeV}]} \right)$$

Note dependence on L / E

Motivation: Neutrino Physics

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} \approx \begin{pmatrix} 0.8 & 0.6 & e^{i\delta} \sin \theta_{13} \\ -0.4 & 0.6 & 0.7 \\ 0.4 & -0.6 & 0.7 \end{pmatrix} \cdot \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

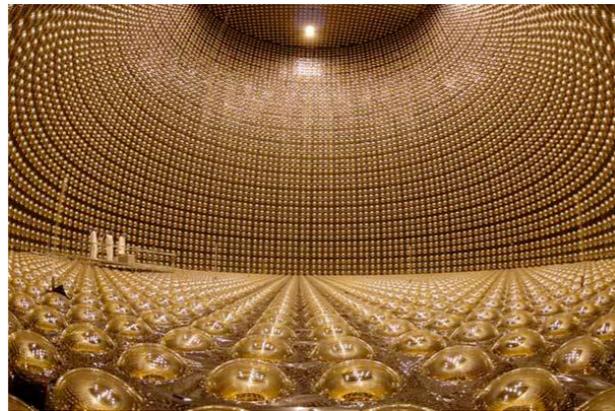
Flavor eigenstates

PMNS matrix

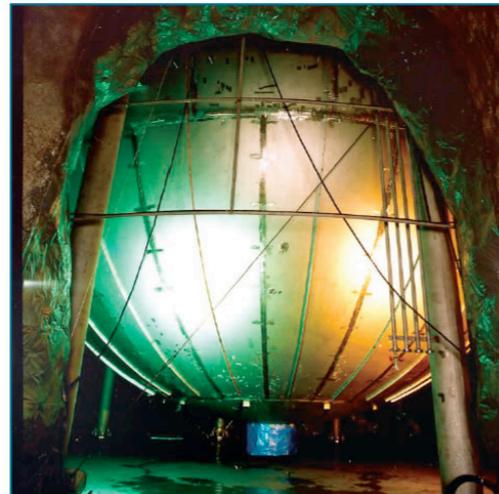
Mass eigenstates

-Neutrinos, born via the weak interaction, are superpositions of mass eigenstates.

$-\theta_{23}$ obtained from Super K, MINOS



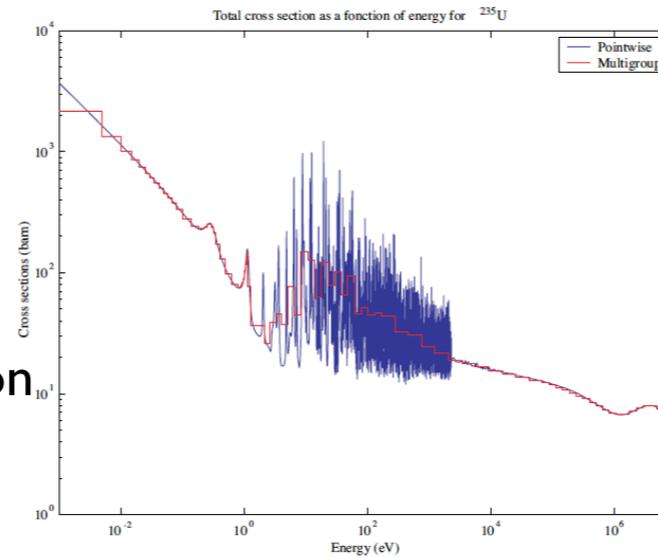
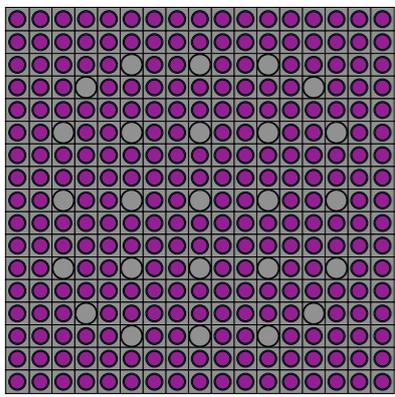
$-\theta_{12}$ obtained from solar neutrino experiments, KamLAND



$$\sin^2 2\theta_{13} < 0.19$$

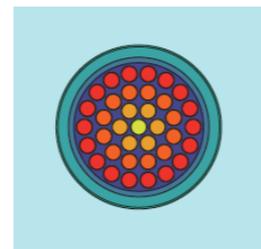
We only have an upper limit for θ_{13} ! (from CHOOZ)

How DRAGON Works



LIB:
Input cross section information

GEO:
Generate reactor geometry



EDI:
cell homogenization & condensation

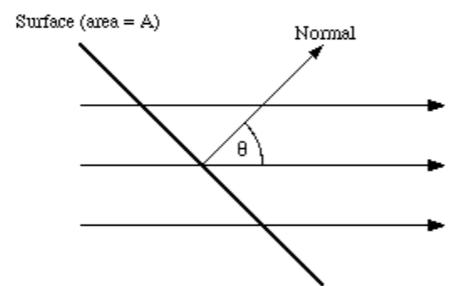
SHI:
calculate self-shielding

EVO:
Calculate depletion / burnup

Fission Rates

$$\phi_i^g = \sum_{\alpha=1}^{N_S} p_{i\alpha}^g \phi_{-, \alpha}^g + \sum_{j=1}^{N_V} p_{ij}^g q_j^g$$

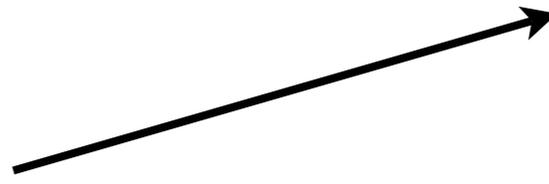
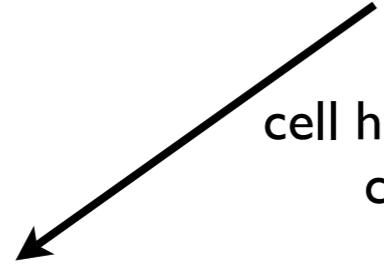
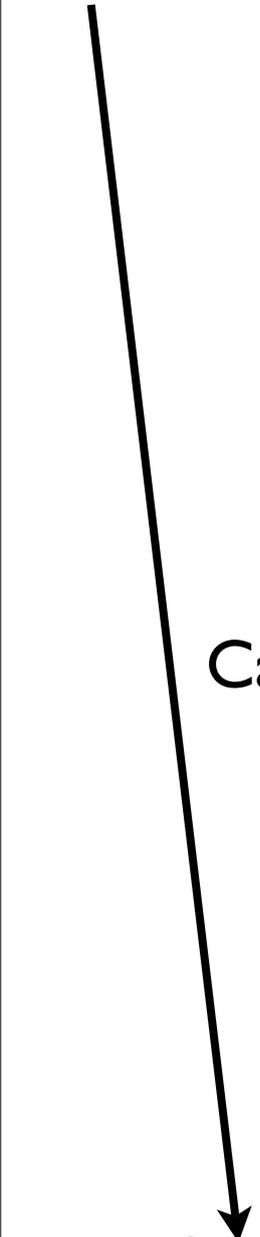
$$\phi_{+, \alpha}^g = \sum_{\beta=1}^{N_S} p_{\alpha\beta}^g \phi_{-, \beta}^g + \sum_{j=1}^{N_V} p_{\alpha j}^g q_j^g$$



NXT:
Generate integration lines (tracking module)

ASM:
Uses tracking to calculate collision probabilities

FLU:
Solve for neutron flux



“2+1”-D DRAGON vs. 3-D MURE: Fission Rates

